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Full Length Research Paper

Development and technical validation of spray kit for coffee harvester

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Spraying a coffee plantation simultaneously with harvesting ensures that the coffee plants are protected from pests and diseases, which are intensified during this period. In addition to economical operation, the pulverizer adapted to all harvester models promotes greater uniformity in pulverized syrup dispensing since the spray tips are arranged evenly around the plant. Two experiments were carried out in the municipality of Capelinha and Varjão de Minas, MG, comparing the Pulverizer Kit with two volumes of syrup to the Arbus 2000 standard and Arbus 2000 Cerrado, respectively in experiment 2. The experiments were conducted using a randomized block design, with seven and ten replications, respectively, for plots of 20 plants to evaluate the deposition of the syrup in the upper, middle, and lower thirds of the plants. It was concluded that the Sprayer Kit adapted to the coffee harvester is a suitable option for spraying simultaneously to the harvest, using syrup volumes lower than those commonly used in coffee cultivation. The application with Arbus 2,000 had difficulty in reaching the upper third of the coffee tree, whereas this did not occur when the coffee was pulverized using the Spray Kit, regardless of the volume of syrup used.

Key words: coffee harvest, application technology, syrup volume.

INTRODUCTION

There are several challenges for the application of phyto- sanitary products during coffee cultivation, particularly

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in relation to uniform syrup deposition in tall plants, and the reduction of drift. The plant architecture and the large index of leaf area make it difficult to cover the leaves with the active ingredient (Silva et al., 2014a). Silva et al. (2014a) reported that the volume of the syrup must be adjusted in order to allow a satisfactory wetting of the leaves and minimizing loss of drops to the soil. Ramos et al. (2007) described the main difficulties to success in perennial cultures as plant size and number of leaves.

Sasaki et al. (2013) found that the main obstacles to the successful application of agrochemicals are due to coffee architecture (plant size and crown density), which forces research and the market to seek new technologies and/or adaptations of application techniques to solve the problem. In general, deposition is lower in the lower and inner parts of the crop canopy due to the umbrella effect provided by higher parts of the crown in some plant species (Silva et al., 2014b). Deposition is also impaired in the upper parts (upper third) of the crown, because the distance that the spray traverses is high, especially in sprayers with spray in the shape of an arc (Santinato et al., 2014b). Santinato et al. (2017a) studied various traditional ways of improving the efficiency of coffee sprays using syrup volumes, adjuvants and hydraulic tips and their results showed the extreme difficulty in achieving good results, especially in large-scale adult crops. They also found that the spray drift loss is very large, contaminating the environment.

After coffee harvesting, whether mechanical or manual, severe damage to the plants occurs, including trunk discarding, operational defoliation, breaking of branches, and falling of flower buds (Santinato et al., 2014a; Carvalho et al., 2016) since coffee harvesting process are often subjected to vibrations (Souza et al, 2018). Such damages serve as a gateway for pests and diseases that promote injury to the crop. Spraying is usually delayed due to the high demand for machinery during the harvest. When protective sprays are slow to occur, economic damage tends to be high because of the poor sanitation of the crop, which requires more combat spraying than usual in an attempt to maintain sound agriculture (Matiello et al., 2010).

An alternative to correct this deficiency in coffee plantations is to combine harvesting and spraying operations, reducing the effect of drift and the volume of syrup, and thereby contributing to the environment. The drift of phytosanitary products is one of the major problems of modern agriculture (Nuyttens et al., 2011). This wastes products and increases environmental contamination, constituting a point of failure of the operation, which must be corrected.

Another parameter of great importance in sprays is the size of the droplets-a decisive factor in deposition both inside and outside the target. This is one of the main factors related to the loss of phytosanitary products to the environment (Fritz et al., 2012). According to Viana et al. (2010), it would be possible to obtain a uniform distribution with a given diameter and number of drops, achieving success in an application, even with a smaller applied volume.

In the present work, a prototype spray was developed, adapted to the coffee harvester, and capable of simultaneously spraying the harvesting operation. The deposition of the syrup promoted by the prototype under two working pressures was evaluated in two experiments against the existing standard in the hydropneumatic sprayers, Arbus 2000 and Arbus 2000 Cerrado.

MATERIALS AND METHODS

The prototype was developed in Mundo Novo Aliança, located in the municipality of Capelinha, MG (Figure 1). The equipment was divided into two sectors, with completely individualized systems, each one located in opposite sides each on one side of the harvester. Each sector consisted of a support, with capacity for 1.000 kg (1), a tank of 200 L (2), an electric motor (3) that provides the necessary pressure for the spraying, and two stems equipped with spray nozzles (4), forming an angle of 90°. The vertical and horizontal rods are 3.2 and 1.6 m long and are provided with 8 and 2 nozzles, respectively. The nozzles were equidistant at 0.4 m. A 100-mesh filter and BD02 tip were used in each nozzle.

Experiment 1 was carried out in the municipality of Capelinha, MG, Brazil, in the cultivation of Cultivar Catuaí Vermelho IAC 144, 9 years of age, 2.8 m high, 1.5 m wide, and a hanging load of approximately 1,800 kg ha^{-1}. The crop was planted at a spacing of 4.0 m between rows and 0.5 m between plants (5,000 plants per ha) with a slope of 15%. The experimental design was a randomized block design with a split plot arrangement, considering the treatments T1, T2, and T3 as main, with 7 replications, totaling 21 plots. The treatments studied were Arbus 2000 with 500 kPa of pressure and syrup volume of 506 L ha^{-1} (T1) like the standard treatment; Spray kit with 100 kPa pressure and syringe volume of 308 L ha^{-1} (T2); Spray kit with 400 kPa pressure and syringe volume of 616 L ha^{-1} (T3). The third, upper, middle, and lower sites were the secondary treatments. The plots were equidistant at 20 m and each was composed of 20 plants.

The spray kit was installed on a K3, Jacto harvester with 7,220 h of use, operating at 1500 m h^{-1}, with 14 magnojet BD02 fan-type tips (110°). The Arbus 2000 was driven by a Massey Ferguson tractor, model MF 265, 4 × 2 TDA, with a nominal power of 47.8 kW (65 hp) operating at a speed of 5000 m h^{-1}, with the L3 gear at 2000 rpm in the engine. The Arbus was endowed with 20 J A^{-1} (black) Jacto (80°) brand cone tips.

It was installed in the municipality of Varjão de Minas, Minas Gerais State, Brazil, under cultivation at Catuaí Vermelho IAC 144, 11 years old, 2.5 m tall, 1.7 m wide, and spaced 3.8 × 0.5 m totaling 5,263 plants ha^{-1}, with a slope of 9%. The Spray Kit with 405 (T1) and 324 L ha^{-1} (T2) was compared to the Arbus 2000 Cerrado by spraying with a volume of 560 L ha^{-1} with 500 KPa of pressure (T3). In the two treatments that used the Kit, the pressure was set at 300 KPa, which in previous tests was the most adequate for the uniformity of the drops. In T1 and T2 the harvester/Kit was operated at 1600 and 2000 m h^{-1}, obtaining in this way the desired volumes of syrup. The treatments had 10 replications and were outlined in randomized blocks, in plots of 20 plants, equidistant at 20 m.

In this second experiment, the Sprayer Kit was installed in a K3,

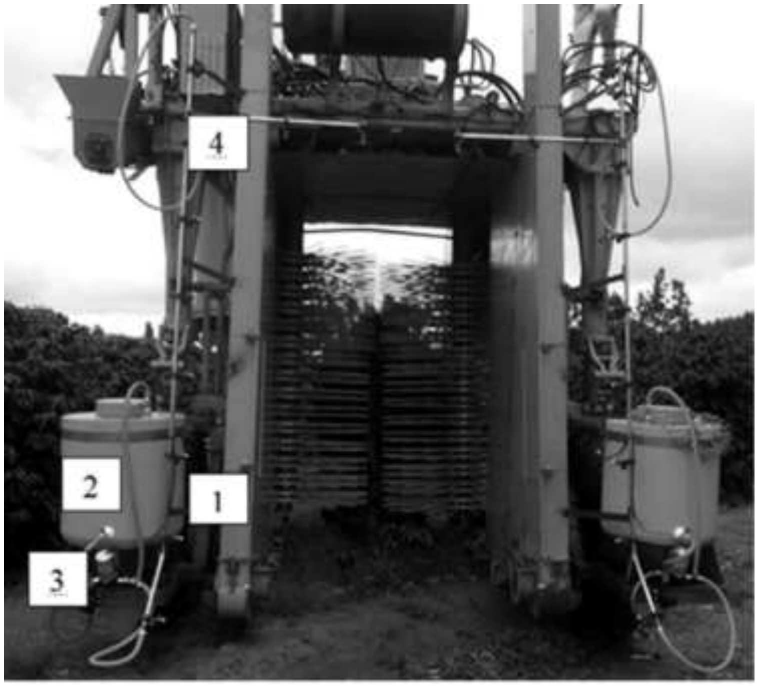

Figure 1. Sprayer kit for coffee harvester and its constituent parts. 1, Support, with capacity for 1.000 kg; 2, Tank of 200 L; 3, Electric motor; 4, Stems equipped with spray nozzles.

Jacto harvester with 5,110 h of use, and 14 magnojet BD02 fan-type tips (110°). The Arbus 2000 Cerrado was driven by a 4 × 2 TDA (John Deere 5425N) tractor, with a nominal power of 55.2 kW (75 hp) operating at an average speed of 4000 m h^{-1} with the L3 gear at 1,400 rpm on the engine. The Arbus was endowed with 24 J A^{-1} (black) Jacto (80°) brand cone tips.

At the time of application, the relative air humidity was 84 and 70%, the winds were 3.0 and 4.4 km h^{-1}, and the temperature 22 and 24°C, therefore, ideal for spraying.

In both experiments, the quality of application parameter measured was the deposition of syrup. For the analysis of the deposition of the syrup on the leaves, aqueous tracer solution, constituted by the food colorant Azul Brilhante, at the dilution of 3,000 mg L^{-1} was sprayed.

At each sampling point (thirds of the plant), ten leaves were collected. Thereafter, they were packed in plastic bags, washed in 100 mL of deionized water, and shaken for 30 s. Subsequently, the absorbance was determined by spectrophotometric laboratory analysis. A wavelength of 630 nm was used in the spectrophotometer readings (Silva et al., 2014b).

The calibration of the spectrophotometer was performed by constructing a standard curve, which consisted in determining the absorbance of solutions having known concentrations of the dye. In order to obtain these solutions, dilutions of the syrup used in the spray containing 3,000 mg L^{-1} of dye were carried out. The regression equation of the standard curve was used to convert the absorbance to dye concentration. From the concentration of the dye in the washing solution, the volume of water used to wash the leaves (100 mL), and concentration of the solution applied (3,000 mg L^{-1}), it was possible to determine the deposit of the solution by Equation 1 proposed by Limberger (2006):

$$D = \frac{10^6 x[\text{solution}]}{\text{Ax}[\text{spray syringe}]} \quad (1)$$

Where, D = syrup deposition (µl); V = volume of water used to wash the leaves (L); [solution] = concentration of the dye in the wash solution (mg L^{-1}); A = leaf area of the segment (cm^2); [syrup] = concentration of the dye in the spray syringe (mg L^{-1}).

After being washed, the leaves had the determined leaf area (cm^2) using ruler. For this measurement, the leaf length and width were multiplied by 0.66, as indicated by Matiello et al. (2010). Then, according to the methodology proposed by Palladini (2000) and cited by Souza et al. (2007), the deposition of the dye per unit area (µL cm^{-2}) was determined, relating the deposition with the obtained leaf area. The deposition was analyzed separately considering subdivided plots, where the plots were the treatments and the subplots were the thirds of the plants (lower, medium, and higher), totaling 63 and 90 experimental units, respectively. The data were submitted to analysis of variance by the F test and when appropriate, the Tukey test was performed, both at 5% significance.

RESULTS AND DISCUSSION

In experiment 1, the application using Arbus 2000 obtained the lowest values of syrup deposition for the average of thirds (Table 1). The deposition of this treatment was lower than the treatments that used 308

Table 1. Deposition of the pulverized syrup in the thirds of the coffee tree, according to the equipment used in experiment 1, Capelinha, MG.

Treatments	Deposition of syrup (µl cm^{-2})			
	Botton	Medium	Higher	Average of thirds
Arbus 2.000 (506 L ha^{-1})	0.218 ^{bA}	0.153 ^{cA}	0.058 ^{cB}	0.143 ^{b}
Spray kit (308 L ha^{-1})	0.406 ^{aA}	0.337 ^{bA}	0.262 ^{aA}	0.335 ^{a}
Spray kit (616 L ha^{-1})	0.375 ^{abAB}	0.501 ^{aA}	0.323 ^{aB}	0.399 ^{a}
CV (%)		32.83		25.33

*Means followed by the same lowercase letters, in the columns, and upper case, in the lines, do not differ by Tukey test, at 5% probability.

Table 2. Deposition of the pulverized syrup in the thirds of the coffee tree, according to the equipment used in experiment 2, Varjão de Minas, MG.

Treatments	Deposition of syrup (µl cm-2)			
	Botton	Medium	Heigher	Average of thirds
Arbus 2.000 Cerrado (560 L ha^{-1})	210.6 ^{aA}	213.1 ^{aA}	129.1 ^{cB}	184.26 ^{b}
Spray kit (405 L ha^{-1})	181.3 ^{abA}	224.1 ^{aA}	237.6 ^{aA}	214.13 ^{a}
Spray kit (324 L ha^{-1})	148.35 ^{bA}	215.3 ^{aA}	161.6 ^{bA}	171.75 ^{b}
CV (%)		39.22		18.19

*Means followed by the same lowercase letters, in the columns, and upper case, in the lines, do not differ by Tukey test, at 5% probability.

and 616 L ha^{-1} (lower volume and superior to the conventional system, respectively), demonstrating that the cause of this low deposition was not the volume of syrup but the structure of the equipment.

The arbus structure of Arbus 2,000 hinders the deposition of syrup when compared to the vertical structure of the Sprayer Kit (Sasaki et al. 2013). In the average of the thirds, there was no difference between treatments T2 and T3 for the deposition of syrup. This gives the viability of using the syrup volume of 308 L ha^{-1}, lower than the other evaluations. This result corroborates that of Ferreira et al. (2013), which enabled the reduction of the volume of syrup applied by modifying the arc structure of the sprayer.

It was observed that in the largest volume of the syrup (T3), the deposition was 48.66% higher in the middle third of the plants. This is commonly observed in sprays that use higher volume of syrup (Santinato et al., 2014b). In spite of this, the higher volume of syrup did not increase the deposition in the lower and upper thirds of the plants.

It was also observed that the Sprayer Kit, in the lowest volume tested, obtained the best distribution of the syrup, with no difference in the deposition for the evaluated thirds. Otherwise, the other treatments had lower deposition in the upper third. This was due to the difficulty presented by Arbus 2000 by the distance between the tips and the target, in reaching the upper third, a fact pointed out by Scudeler et al. (2004). In the case of the Spray Kit with a volume of 616 L ha^{-1}, this fact does not condemn the spraying, since the deposition, however uneven, was adequate. What happened was justified by the predominance of the syrup in the middle third that was elevated.

In experiment 2 (Table 2), there was a higher deposition of syrup in the lower third, in the treatment that used Arbus 2000 Cerrado. This was probably due to the higher volume of syrup used and also the high speed of the equipment turbine that allows greater mobility of the coffee leaves, overcoming the difficulty imposed by the “umbrella” effect. In the background was the Spray Kit in the largest syrup volume followed by the lowest syrup volume.

In the middle third, there was no difference between treatments. This fact shows that in this third, regardless of the volume of the syrup used (324, 405 and 560 L ha^{-1}), the deposit was satisfactory.

In the upper third, the largest syrup deposition was obtained using the Sprayer kit with the largest volume of syrup used, followed by the same equipment with the lowest syrup volume and both higher than the Arbus 2000 Cerrado, with the lowest value. Again, the inferior quality of the upper third was obtained using the arbor sprayer, even if it was of the Cerrado model, equipped with branches with tips positioned at a height higher than conventional Arbus (Table 2).

Comparing the uniformity of spray distribution, large differences were observed in the Arbus 2000 Cerrado treatment, with much higher deposition in the lower and middle thirds, compared to the upper third. In the Sprayer Kit operating with the lowest volume of syrup, a uniform syrup was deposited. This was due to the high deposition in the middle third, which was superior to the lower and upper thirds, which did not differ from itself. In the treatment that used the Sprayer Kit with the largest sample volume tested, satisfactory uniformity occurred across the entire plant. This is due to the arrangement of the nozzles and the volume of syrup used (Table 2).

In general, the Spray Kit with 324 L ha^{-1} obtained a similar deposition to that of the Arbus Cerrado, with 560 L ha^{-1}, and both had lower deposition than the 405 L ha^{-1} Sprayer Kit.

In general, comparing the two areas studied, the results were positive for the Spray Kit. However, in each type of crop, adjustments must be made in relation to the volume of syrup, pressure and hydraulic tips used to obtain the best possible results. Santinato et al. (2016) did a study in crops of several vegetative volumes and verified that in each of them a specific volume of syrup is required.

Conclusions

The Sprayer Kit adapted to the coffee harvester is suitable for simultaneous spraying with a low volume of the syrup and with the deposition and distribution of the regular syrup. This work examined the deficiency in uniformity of syrup distribution of arc sprayers.

The technique studied here presented practical and economic benefits, for doing two operations at the same time, for improving the efficiency of the pulverization and environmental ones by using smaller volume of syrup and reducing the drift of the products for the environment.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Pig compost for the formation of coffee seedlings in the substrate composition

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Pigs can be used in the formation of coffee seedlings; it gradually provides essential nutrients for the development of plants, in addition to promoting the improvement of the substrate and water retention. It was decided, with this work, to evaluate the use of pig compost in the formation of coffee seedlings. The topics studied were: T1 - Witness (absence of organic compound); T2-30% concentration of cattle compost; T3-15% concentration of pig compost; T4 - 30% concentration of pig compost; T5 - 45% concentration of pig compost. The five treatments were arranged in a randomized block design, with five replications. The best treatment for plant height and collection diameter was 45% of pig compost. The best results for the total dry matter were obtained with treatments with 30 and 45% of pig compost. The compost based on pig manure at 30% stood out in comparison to the standard cattle manure at 30%, providing higher levels of M, O, P, Mg and micronutrients (B, Cu, Mn, Zn). The use of 30 or 45% of manure-based compost produces coffee seedlings similar to the 30% of cattle manure composting.

Key words: Dejects, organic matter, *Coffea arabica.*

INTRODUCTION

The use of organic matter in the substrate composition for the formation of coffee seedlings is essential for its proper development (Dias et al., 2009; Almeida et al., 2011). The organic matter improves the physical, chemical and biological characteristics of the soil (Malavolta, 2006). According to Araujo et al. (2007) the use of organic matter promotes an increase in the N, K and Mg leaf contents. In plantations already implanted the organic compound must also be supplied, because it improves the physical conditions of the soil, retains more water and provides nutrients gradually, when appropriate doses of the organic compound are used, the levels of post-planting chemical fertilizers can be reduced by 30 to 50%, this recommendation should take into account not

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only the soil characteristics, but also the nutrient demand of the plant (Matiello et al., 2010).

According to Clemente et al. (2008) coffee plantations with one year post-planting the critical ranges of macronutrients are: nitrogen 19.24 to 23.16 $g.kg^{-1}$; phosphorus 1.14 to 1.21 $g.kg^{-1}$; potassium 17.39 to 19.02 $g.kg^{-1}$; calcium 12.70 to 14.11 $g.kg^{-1}$; magnesium 8.26 to 8.97 $g.kg^{-1}$; and sulfur 1.49 to 1.77 $g.kg^{-1}$. The critical ranges of micronutrient concentrations in coffee leaves are: copper 11 to 14 mg kg^{-1}; iron 100 to 130 mg kg^{-1}; zinc 15 to 20 mg kg^{-1}; manganese 80 to 100 mg kg^{-1} and Boron 50 to 60 mg kg^{-1} (Malavolta et al., 1997). According to the nutritional demand of the coffee tree, it is advisable to associate organic compounds and fertilizers to obtain a balance that generates good productivity, but which maintains adequate soil physical and chemical characteristics (Fernandes et al., 2013a).

Among the available sources, the most common is the cattle compost, with 30% of the substrate being used. Cattle compost provides substrate aeration, adequate nutrients supply and satisfactory water retention, being superior to sources such as poultry compost (Fernandes et al., 2013a) and coffee straw (Fernandes et al., 2013b). Poultry compost does not provide the same aeration and the coffee straw, in addition to the higher C/N ratio, does not have adequate nutrient ratios (Matiello et al., 2010).

An alternative source to cattle compost would be the one originated by pigs, available in many Brazilian regions. When associated with other materials, they form a rich in nutrients compost and can meet the coffee seedlings nutritional requirements. However, no studies were found evaluating the agronomic potential of pig compost in the production of coffee seedlings. The hypothesis that emerges would be that by improving the chemical properties of the soil and the nutritional status of the plants with the pig compost, it favors the growth and quality of the seedlings in a similar way to the cattle compost. Therefore, the aim here was to study the proportion of pig compost compared to the cattle compost in the soil, nutritional status, growth and quality of coffee seedlings.

MATERIALS AND METHODS

The experiment was installed in a coffee nursery located in Campo Experimental Francisco Pinheiro Campos, located in the municipality of Patos de Minas, Minas Gerais, Brazil; with a 50% shading polypropylene mesh cover. The coffee seedlings were produced in polyethylene bags, with a volume of 1.693 cm^3. For the preparation of the substrate, the fertilization used in all treatments corresponded to: 1.0 kg m^{-3} of P_2O_5 and 0.6 kg m^{-3} of K_2O, using as sources single superphosphate (24% of P_2O_5) and potassium chloride (60% K_2O) respectively, as indicated by Matiello et al. (2010). The interior of each bag at 2 cm depth was seeded with two coffee seeds from Catuaí Vermelho IAC 144 on September 06, 2014.

The treatments studied refer to different substrate compositions of the seedlings: T1 - Witness (absence of organic compound); T2 - 30% concentration of cattle compost, considered Standard MAPA/Procafé; T3-15% concentration of pig compost; T4 - 30% concentration of pig compost; T5- 45% concentration of pig compost. The five treatments were arranged in a randomized block design, with five replications, totaling 20 plots. Each plot was composed of 20 plants, with the main eight being useful for evaluations. Between each plot there were plants to compose the double borders. The organic sources used were analyzed as organic fertilizer according to the Normative Instruction 27 (MAPA). The organic sources were mixed with samples of a dystroferric Red Latosol (EMBRAPA, 2006) with a layer of 0.1 to 0.2 m depth where it was sieved (5 mm mesh) and employed according to the proportions equivalent to each treatment. The seedlings were irrigated by sprinklers with a 70.0 L h^{-1} flow rate, maintaining the containers with 80% field capacity throughout the entire production period (180 days). The following evaluations were carried out 180 days after sowing: biometry (plant height and collection diameter) and it determined the contents of: N, P, K, Ca, Mg, S, B, Cu, Fe, Mn, Zn and Na in the 3^{rd}, 4^{th} and 5^{th} pairs of leaves and the shoot, root and whole plant (total) of the dry matter production. Samples of properly homogenized substrate were collected and the pH values and the contents of O.M., P, K, Ca, Mg, S, B, Cu, Fe, Mn, Zn and Na were determined according to the methodology described by Raij et al. (2001). The quality indexes of seedlings evaluated were between plant height and collection diameter (RAD) and the Dickson quality index (IQD), calculated according to the Equations 1 and 2, respectively (Dickson et al., 1960).

$$RHD = \frac{H}{CD} \tag{1}$$

$$DQS = \frac{TDM}{RHD + \frac{DMA}{DMR}} \tag{2}$$

On what:
RHD = Ratio between plant height and collection diameter;
H = Plant height (cm);
CD = Collection diameter (mm);
DQS = Dickson Quality Score;
TDM = Total Dry Matter (g $plant^{-1}$);
DMA = Dry Matter of the Aerial Part (g $plant^{-1}$);
DMR = Dry matter of the Root System (g $plant^{-1}$).
The data were submitted to analysis of variance and, when appropriate, to the Tukey test, both with 5% of significance. The statistical program SISVAR (Ferreira, 2011) was used for that.

RESULTS AND DISCUSSION

The application of 45% pig compound promoted a higher M.O. of the soil in relation to the other treatments, followed by the pig and cattle composts with 30% each, and the pig compost with 15%, all higher than the control (Table 1). It was observed that the use of organic compost increased the soil pH value in relation to the control, highlighting the pig compost in the ratio of 45 and 30% and the bovine compost (Table 1). There are reports in literature showing a decrease in the pH due to the increase in M.O. (Fernandes et al., 2013a, b). The use of the pig compost independently of the concentration in the substrate promoted a higher P content in relation to the other treatments (Table 1). It

Table 1. Results of the chemical properties of the soil as a function of the organic compound treatments in the formation of the substrate for the production of coffee seedlings.

Treatments	dag kg^{1}	$CaCl_2$	mg dm^{3}		mmol$_c$ dm^{3}			%
	MO	pH	P	K	Ca	Mg	H + Al	V
T1 – C	14.5^{d}	5.4^{c}	538.5^{b}	4.4^{b}	33.0^{b}	2.7e	30.2^{a}	57.2^{c}
T2 – E30	43.5^{b}	5.9^{b}	585.7^{b}	10.6^{a}	70.0^{a}	23.2^{d}	19.2^{b}	84.5^{b}
T3 – S15	36.0^{c}	6.6^{a}	1121.7^{a}	10.9^{a}	62.2^{a}	32.2^{c}	14.2^{c}	88.2^{a}
T4 – S30	49.2^{b}	6.8^{a}	1490.0^{a}	10.0^{a}	69.2^{a}	51.7^{b}	13.7^{c}	90.5^{a}
T5 – S45	63.3^{a}	6.1^{b}	1385.3^{a}	6.3^{ab}	62.6^{a}	81.3^{a}	19.0^{b}	89.0^{a}
CV (%)	7.14	2.87	22.1	28.03	6.05	9.7	10.3	1.9

* Means followed by the same lowercase letters, compared in the columns, do not differ from each other, by the Tukey test at 5% significance.

was observed that the P content of the soil with the use of the pig compost was of 137 to 155% higher than the cattle compost, a fact that is explained by the high nutrient content in the pig compost.

An increase of the calcium contents in all the treatments fertilized with organic sources was observed in relation to the control (Table 1). The increase of the pig compost concentration reflected in the increase of the Mg content in the soil, showing a lower nutrient content with the use of cattle compost; and all of them differed from the control. The higher content of Mg in the soil due to the use of pig-based organic compost could be explained by the higher content of this nutrient in the compost. The exchangeable acidity was higher in the control and lower in the fertilized treatments. The proportions of 15 and 30% of pig compost obtained the lowest levels. The content of Ca present in the treatments fertilized with organic composts was practically double from the control (Table 1) given the presence of the element in the composts. The relation between the increase in Ca content and the reduction of exchangeable acidity had already been studied in other coffee seedlings production papers (Dias et al., 2009; Almeida et al., 2011). Regarding the V%, all the treatments that used the pig compost were superior to the standard, which in turn was superior to the control. For S the best treatments were 45 and 30% of pig compost, respectively, and all were superior to the control (Table 1).

Concerning the B content, there was no difference between the treatments with 30% of cattle compost and 15 and 30% of pig compost. It was observed that in all the treatments, the B contents were greater than control, and there was a reduction of the content in the greater dosage of the pig compost (Table 2). The Cu content was higher in the treatments fertilized with pig compost, which increased with the content. There was no difference between the cattle compost treatment and the control. The highest dose of the pig compost had a Cu content of 1636.25 and 1118.42% higher than the control and the cattle compost, respectively (Table 2). For the Fe content, the cattle compost and pig compost in the 45% ratio were the best treatments. The smaller proportions obtained lower levels. However, they were superior to the control. For the Mn content, there was an increase in the content due to the increase in the proportion of pig compost. All treatments fertilized with it were higher than the cattle compost and the witness (Table 2). For the Zn content, all the treatments fertilized with the pig compost were superior to the control and to the standard, with an emphasis on the treatment with the use of 30% of pig compost. As for the B content, the higher proportion of the pig compost reduced the Zn content in relation to the 30% ratio. It is possible that this has occurred because the high proportion of compost induced high O.M. content, which could compress the zinc and decrease its availability in the soil (Table 2).

The contents obtained with the fertilized treatments are within the appropriate ranges for the coffee, both for macro (Gonçalves et al., 2009) and for micronutrients (Gontijo et al., 2007). The control treatment, on the other hand, obtained contents less than adequate for N (Table 2). For the N content, all fertilized treatments were superior to the control. For P, the highest content was 15% of the compost. For the Ca content, the best treatment was 30% of the cattle compost. The best treatments for the Mg content were 30 and 45% of the pig compost. There were no differences between treatments for K, S, B, Cu, Fe, Mn, Zn and Na (Table 3). All the treatments fertilized with organic sources obtained plant height and diameter superior to the control. The best treatment for plant height was 45% of pig compost. The best results for collecting diameter were obtained with the pig compost. A great increase was observed in the collection diameter when 45% of pig compost was used, with a 50 to 19% value higher than the control and the standard, respectively (Table 4). The additions obtained in the treatments are the reflection of the higher nutrient levels in the soil provided by the tested fertilizers. The most important difference in the collection diameter was due to the Mg, Mn and Cu contents, which were highlighted with the use of 45% of the pig compost (Prado, 2008).

The use of organic sources in the substrate

Table 2. Micronutrient results as a function of the organic compound treatments in the substrate formation for coffee seedlings production.

Treatments	mg dm^3					
	S	B	Cu	Fe	Mn	Zn
T1	13.2^b	0.5^c	2.4^c	19.0^c	5.7^d	5.3^d
T2	18.5^{ab}	1.6^a	3.4^c	84.5^a	7.1^{cd}	10.1^d
T3	24.0^{ab}	1.6^a	19.7^b	47.0^b	13.9^{bc}	99.0^c
T4	28.5^a	1.7^a	34.4^a	55.5^b	16.1^b	158.0^a
T5	24.3^{ab}	1.0^b	41.6^a	76.0^a	26.4^a	130.6^b
CV (%)	22.6	14.9	17.6	12.8	22.7	14.5

* Means followed by the same lowercase letters, compared in the columns, do not differ from each other, by the Tukey test at 5% significance.

Table 3. Nutrient and sodium leaf content as a function of the treatments in the substrate formation for the production of coffee seedlings.

Treatmets	Leaf content (g kg^{-1})											
	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn	Na
T1	16.1^b	2.7^{ab}	36.2^a	8.1^b	2.1^c	2.2^a	55.8^a	290.5^a	1420.0^a	41.2^{ab}	49.2^a	264.0^a
T2	27.0^a	2.9^{ab}	41.2^a	10^a	3.3^{bc}	1.7^a	53.7^a	265.5^a	1072.5^a	28.7^b	39.5^a	246.2^a
T3	23.5^a	3.0^a	40.6^a	8.1^b	3.4^b	1.7^a	53.2^a	282.6^a	868.7^a	41.2^{ab}	50.0^a	217.5^a
T4	24.7^a	2.3^{bc}	46.8^a	7.9^b	4.8^a	1.8^a	47.4^a	304.1^a	1086.2^a	38.7^{ab}	52.2^a	278.7^a
T5	25.3^a	1.9^c	38.1^a	8.2^b	5,2^a	1.5^a	39.9^a	296.0^a	1176.2^a	56.2^a	42.3^a	245.0^a
CV (%)	15.63	12.67	15.29	10.9	14.2	21.25	14.37	21.42	34.13	21.57	25.85	19.98

*Means followed by the same lowercase letters, compared in the columns, do not differ from each other, by the Tukey test at 5% significance.

Table 4. Height, collection diameter, and dry matter of coffee seedlings as a function of the treatments used in the formation of the substrate.

Treatments	Height of plants (cm)	Collection diameter (mm)	Dry matter (g plant^{-1})		
			Aerial part	Root system	Total
T1	8.82^c	2.1^b	0.41^c	0.60^a	1.01^c
T2	14.35^b	2.6^{ab}	1.06^b	0.67^a	1.76^b
T3	14.86^{ab}	2.7^a	1.03^b	0.70^a	1.70^b
T4	16.04^{ab}	2.7^a	1.11^b	0.75^a	1.86^{ab}
T5	16.51^a	3.15^a	1.27^a	0.90^a	2.17^a
CV (%)	6.01	9.29	14.91	18.84	10.13

* Means followed by the same lowercase letters, compared in the columns, do not differ from each other, by the Tukey test at 5% significance.

composition of seedlings promoted an increase in dry matter of the aerial and total part, although it did not have statistically effect on the dry matter of the root system. The best results for the total dry matter were obtained with treatments with 30 and 45% of pig compost. This fact is probably justified by the higher levels of P and Ca in substrates fertilized with pig compost, since these nutrients act in the formation of the constituent parts of the plant, notably the P content in the root (Silva and Delatorre, 2009) (Table 3). The supply of P is essential for seedlings with a satisfactory quality index (Santinato et al., 2014), since this is the most important nutrient for the coffee-growing phase (Matiello et al., 2010; Silva et al., 2010) (Table 4). The quality indexes of seedlings have the purpose of making associations between the biometric variables studied in order to propose a definitive and determinant variable. Tall seedlings can present a small amount of root system and vice versa, not being adequate in the same way for the diameter of the stem. The best index value means the plant with the best balance between its constituent parts. These rates are widely used in quality papers about forest species seedlings (Marana et al., 2008; Caione et al., 2012).

For the RAD, which relates only to plant height and collection diameter, all treatments fertilized with organic sources were superior to the control, with no differences

Table 5. Quality indexes of coffee seedlings as a function of the treatments in the substrate formation.

Treatments	Seed quality indexes	
	DQS	RHD
T1	4.24[b]	1.21[b]
T2	5.44[a]	1.25[ab]
T3	5.52[a]	1.24[b]
T4	5.95[a]	1.25[ab]
T5	5.25[a]	1.33[a]
CV (%)	8.81	15.04

* Means followed by the same lowercase letters, compared in the columns, do not differ from each other, by the Tukey test at 5% significance.

Table 6. Pearson correlation between biometrics, dry matter and leaf content parameters, soil fertility parameters with IQD.

Biometry	Pearson
Height of plants	0.46*
Stem diameter	0.76**
Mg content foliar	0.61**
Dry matter of the aerial part	0.52*
Dry matter of the root system	0.89**
Total dry matter	0.77**
M.O content in soil	0.66**
Mg content in soil	0.71**
V%	0.45*
Cu content not alone	0.61**
Fe content in soil	0.56*
Mn content in soil	0.61**

* ns = not significant; * = significant at 5%; ** = significant at 1%.

amongst them. For the IQD, a more complete index, since the biometric parameters were related to dry matters, the best treatment was 45% of pig compost, with the corral compost and the pig compost in the background, both with a 30% level. There was no difference between the witness and 15% of pig compost, so this proportion cannot be recommended. Santinato et al. (2014), in the experiment of P doses in the formation of coffee seedlings obtained similar indexes for the best treatments studied. Ribeiro et al. (2007) and Caldeira et al. (2008) pointed out that when using 100% of the compost in the production of seedlings there was a decrease in the quality of the indexes (Table 5). There was a positive correlation between the height of the plants and the diameter of the stem with the IQD, whether they weak and strong, respectively. Thus, the diameter of the stem is the most appropriate to evaluate coffee seedlings of the biometric parameters (Table 5). Of all leaf contents, only the Mg showed correlation with the IQD, being classified as moderate, that is, leaf contents are not good indicators of seedling quality (Table 5).

The dry matter of the aerial part from the total and root system presented correlations with the IQD, weak, strong and strong, respectively. The main one was the dry matter of the root system, with a correlation coefficient of 0.89, being the parameter of the greatest correlation of all the evaluated in the present study (Table 6). The high correlation of root dry matter and IQD was already pointed out by Marana et al. (2008). The fertility chemical attributes that most influenced the quality of the seedlings were organic matter, Mg, base saturation index, Cu, Fe, Mn, Ca in CTC and Mg in CTC. Of these, the ones who showed most correlation were the Mg, in the same way as in the leaf content, except in this case with a strong correlation. The organic matter content was the one that obtained the biggest correlation in the background, and was also strong. The remainder had a weak correlation (Table 6).

The correlations showed the superiority of the treatments fertilized with pig compost, especially in its greater composition (45%), emphasizing that mainly the content of Mg contained therein (200.0 vs 85.68 mg kg^{-1}) and its constitution with high CTC were fundamental to the quality of seedlings. This huge amount of nutrients that compose the compound can even replace much of the supplemental mineral fertilizer used in the production of seedlings. Santos et al., (2010) they studied the feasibility of partial and total substitution of mineral fertilizers by the use of organic compounds and green manure in the field. In the same direction Fernandes et al. (2013) did the same using chicken manure. Both have come to the conclusion that it is necessary to associate the organic with the mineral for the best results.

The use of pig compost in the formation of the substrate for the production of coffee seedlings is an interesting alternative for those producers that are in pig producing regions, since it is a source of organic matter cheaper and superior in relation to other compounds such as bovine. The use of pig compost in the production of coffee plants, as well as in adult crops, arises from the need to minimize the negative effects that this compound could bring to the environment if it were discarded without any care (Navia et al., 2011). The pig compost can be improved when associated with higher C / N ratio materials, such as coffee straw, which is always available in coffee farms (Nolan et al., 2011).

Conclusions

1). The compost based on 30% pig manure was highlighted in comparison to the standard with 30% cattle manure, providing higher levels of OM, P, Mg and the micronutrients (B, Cu, Mn, Zn) of compost and it reflected in the increase of Mg contents in the aerial part of the coffee tree.
2). The use of 30 or 45% pig manure compost produces coffee seedling similar to the 30% cattle manure compost.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Correlation of climatic elements with phases of the lace bug *Vatiga illudens* (Hemiptera: Tingidae) in two cassava cultivars (*Manihot esculenta* Crantz, Euphorbiaceae)

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Cassava (*Manihot esculenta* Crantz) is subject to various disease problems and insect attacks. The aim of this study was to evaluate the correlations of climatic elements on the phases of the lacebug, *Vatiga illudens* in two cultivars of cassava. The study was carried out in a greenhouse using the 'Sergipana' and 'Campina' cultivars. Data were analyzed using the Pearson index for linear correlations. Comparisons between the cultivars and the insect population were performed using boxplot tests, with 95% confidence intervals. Data were subjected to analysis of variance and were compared using the Tukey test at 5% probability. In cassava phenological stages, height and number of branches were different between the cultivars of. The greatest number of individual lace bugs was found in the 'Campina' cultivar, with an increase in the population during August. Nymphs and adults of *V. illudens* populations varied monthly in 'Sergipana' cultivar with a peak in June and August. There was a significant correlation between the phenological stages of the cassava cultivars and the climatic elements on lace bug population fluctuations in a greenhouse.

Key words: Abiotic factors, lacebug, *Manihot esculenta*, plant production.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz, Euphorbiaceae) is a fruit with various usages, from human and animal food production to industrial uses, serving as an energy base for populations with low human development indices in tropical and subtropical countries (Albuquerque et al., 2009).

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Nevertheless, pests and diseases can significantly compromise the final yield of the crop (El-sharkawy, 2003). About 200 species of arthropods are associated with cassava cultivation, and some insects are specific and resistant to the host plant; however, not all get to the status of pests (Bellotti et al., 2000).

Insects cause injuries in cassava (Bellotti et al., 2012). The protoplasm-sucking species and those that consume the leaves reduce leaf area, decreasing the photosynthetic rate (Farias and Bellotti, 2006). Other pests suck the phloem and xylem contents, weakening the plant (Bellotti and Arias, 2001; Calatayud and Le Rü, 2006). Nevertheless, there are those that attack stems and roots, creating a gateway for diseases (Pietrowski et al., 2010). Therefore, these insects cause reduction of yield and root quality of the cassava (Farias and Bellotti, 2006; Bellotti et al., 2012).

In Brazil, particular pests are the lace bugs *Vatiga manihotae* or *Vatiga illudens* (Hemiptera: Tingidae); the whiteflies Bemisia tuberculata and *Aleurothrixus aepim* (Hemiptera: Aleyrodidae); the mites *Mononychellus tanajoa* and *Tetranychus urticae* (Acari: Tetranychidae); the thrips *Frankliniella williamsi* and *Scirtothrips manihoti* (Thysanoptera: Thripidae); and the beetle *Migdolus fryanus* (Coleoptera: Cerambycidae) (Pietrowski et al., 2010; Bellotti et al., 2012; Wengrat et al., 2015; Embrapa, 2016). Among the pests cited above, the lace bug (Hemiptera: Tingidae) was highlighted which in recent years has been showing visible population growth on cassava plantations (Pietrowski, 2009). It was hypothesized that there is influence of climatic elements on the population dynamics of the lace bug *V. illudens* in cassava cultivars. The objective of this study was to evaluate the correlation of the climatic elements on the population fluctuation of *V. illudens* in two cultivars of cassava in greenhouse conditions.

MATERIALS AND METHODS

The study was carried out in the city of Arapiraca, Alagoas, Northeast of Brazil, with the following geographical coordinates: Latitude 9° 75´ 25´´S and Longitude 36° 60´ 11´´W. The municipality presents edaphoclimatic conditions, with average temperature 28°C; average annual rainfall of 470 mm; the climate of the region is type As', presenting as tropical and hot according to the classification of Köppen and Geiger (Alagoas-Semarh-dmet, 2017).

The experiment was conducted from July/2017 to January/2018. Two cultivars of cassava 'Sergipana' and 'Campina' were grown in a greenhouse with 50% shaded environment. After 15 days, there was seedling emergence (reproduction by cutting). After two months, the lace bug V. illudens was collected. The insects were kept in the greenhouse on the plants and monitored weekly. The experimental design was completely randomized with two treatments (cultivars) and twelve replications.

To monitor insect developmental period, no control method was used against *V. illudens*. Data were recorded weekly in spreadsheets, including the number of nymphs and adults of bedbug per leaf, plant height, number of leaflets, ramifications and stem diameter, variables measured in the experiments, end to evaluation of the phenological development of the two cultivars. The climatic evaluations were recorded using monthly data of precipitation (mm), relative humidity (%), and temperature (°C), provided by the 'Instituto Nacional de Metereologia' (INMET) for 2017 and 2018. The population fluctuation was analyzed by the Pearson index to obtain linear correlations between the numbers of nymphs and adults of *V. illudens*, and for the phenology data of the cultivars and the climatic elements. Boxplots were used to compare the data between the two cultivars and to evaluate the dispersion of the data. The comparison between the cultivars and the sampled populations was performed using boxplot tests with 95% confidence intervals. The data were subjected to analysis of variance and the means were compared by the Tukey test at 5% of probability, using the Assistat - Statistical Analysis System (Silva et al., 2016).

RESULTS AND DISCUSSION

Evaluation of the phenological development of the two cultivars

The phenological development of plants grown in pots in greenhouse conditions showed significant differences in terms of height and branches. The analysis of variance of the cultivars data showed a significant difference by the $F = 9.3807$ * test at the 1% probability level ($p < 0.05$) (Table 1). Vidigal Filho et al. (2000), working with cultivated data in the field, compared the height of cultivars IAC 12, IAC 13, IAC 14, Fécula Branca, Espeto, Branca de Santa Catarina, and Fibra. The cultivar that presented the highest growth in height during the evaluated period was IAC 14, with height estimated at 20 cm, at 80 DAP, reaching an estimated height of 272 cm, at 320 DAP, making it the largest cultivar at 135 days.

The two cultivars showed no significant difference in terms of leaf numbers and stem diameters. According to Beraldo et al. (2011), the number of leaves on the main stem was associated with the beginning of starch accumulation in the roots. Schons et al. (2007) verified that the cultivar of cassava RS 13 started this accumulation when its stem had 21 leaves very visible, independent of the planting season.

Characteristic branching also influences the mechanization of the crop. Varieties that do not present branching are more amenable to mechanized planting to facilitate crop management (RÓS et al., 2011). According to Beraldo et al. (2011), cultivars with stem and branch can present lower yields in denser spacings, because they require more space to develop their branches and, consequently, to express the potential of photoassimilate production.

Population fluctuations of the lace bug in cultivars

The month of December showed the lowest variability, indicating that the distribution of lace bugs within the greenhouse was low in relation to the months observed (June/2017 and January/2018). Oliveira and Malaguido (2004) found similar data regarding adults and nymphs of various instars of lace bugs found throughout the year,

Table 1. Average data of the phenological development of the two cultivars.

Variety	PH (cm)	L(u)	SD (cm)	B(u)
Sergipana	40.36[a]	14.31[a]	0.76[a]	1.33[a]
Campina	35.05[b]	16.38[a]	0.74[a]	0.54[b]
C.V.%		15.42		

Legend: PH = plant height; L= leaflets; SD= stem diameter; B= Branches. C.V= correlation coefficient. Means followed by the same letter in the column and in the row did not differ significantly by the Tukey test at 5% probability.

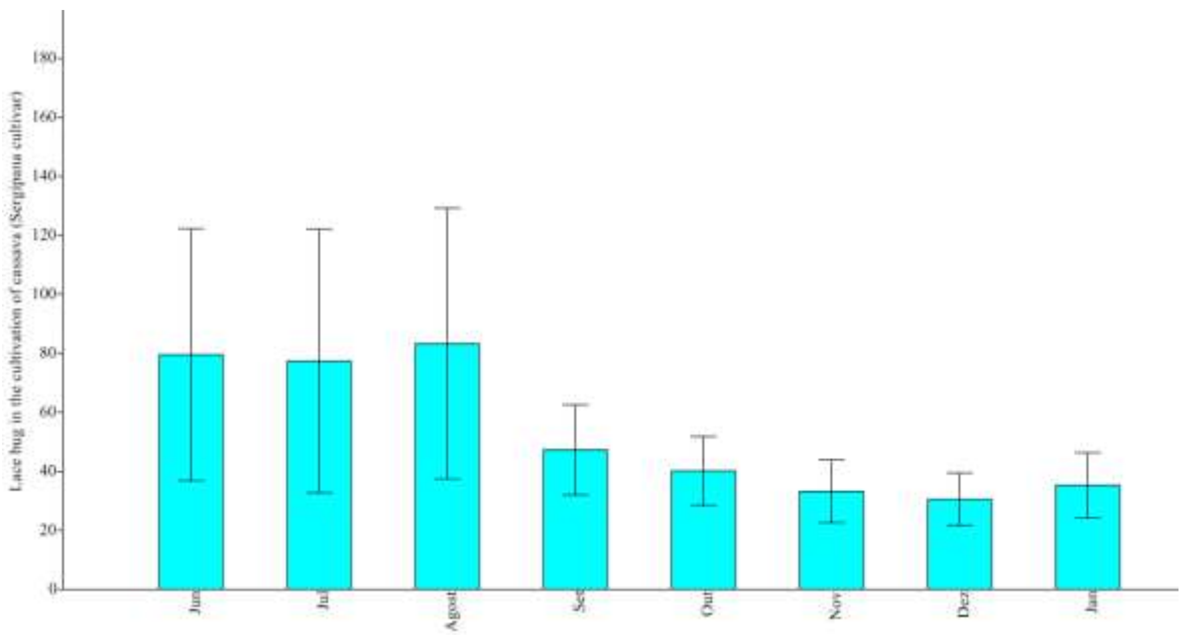

Figure 1. Population monitoring of the income bug during the research (June / 2017-January / 2018) (Sergipana cultivar).
Source: Research data.

although in the drier periods the adult population was lower. The results showed that the population of nymphs and adults of *V. illudens* in the cultivar Sergipana varied throughout the analyzed months, with a peak between June and August (Figure 1).

Although there are still few studies that determine the population fluctuation of the lace bug, studies carried out in various locations with several cassava cultivars in commercial plantations have shown that the population peaks of this pest insect can occur between the months of November to July (Vitório et al., 2005; Rohden et al., 2005; Martinazzo et al., 2007; Rheinheimer et al., 2012).

In the western region of Paraná, the population is recorded in the crops from November, presenting higher population peaks between January and March (Martinazzo et al., 2007); whereas for the Federal District, (Oliveira et al., 2001) and in Bahia, the peak occurs between September and October (Farias et al., 2007).

The boxplot for the month of October (Figure 2) showed lower variability in the Campina cultivar, indicating that lace bug distribution was relatively low in relation to the months observed. The highest number of individuals of lace bugs in the Campina cultivar was in August. According to Martinazzo et al. (2007), the behavior of the lace bug in this winter period remains unknown, and it is unclear whether the insect enters diapause in the cultural remnant of the area or if there is a migration to refuge areas. A factor that can also be related to these differences of attack of *V. illudens* among the cultivars are the contents of cyanogenic compounds in plants, a fact verified by Santos et al. (2008) who observed that the higher the hydrocyanic acid content (HCN) in cassava roots, the lower the incidence of nymphs and adults of *V. illudens*. Nevertheless, in the present work, the cyanogenic contents of the studied materials were not assessed.

According to Bellon (2013) in the first cycle of cassava, the population of nymphs had its peak population in the

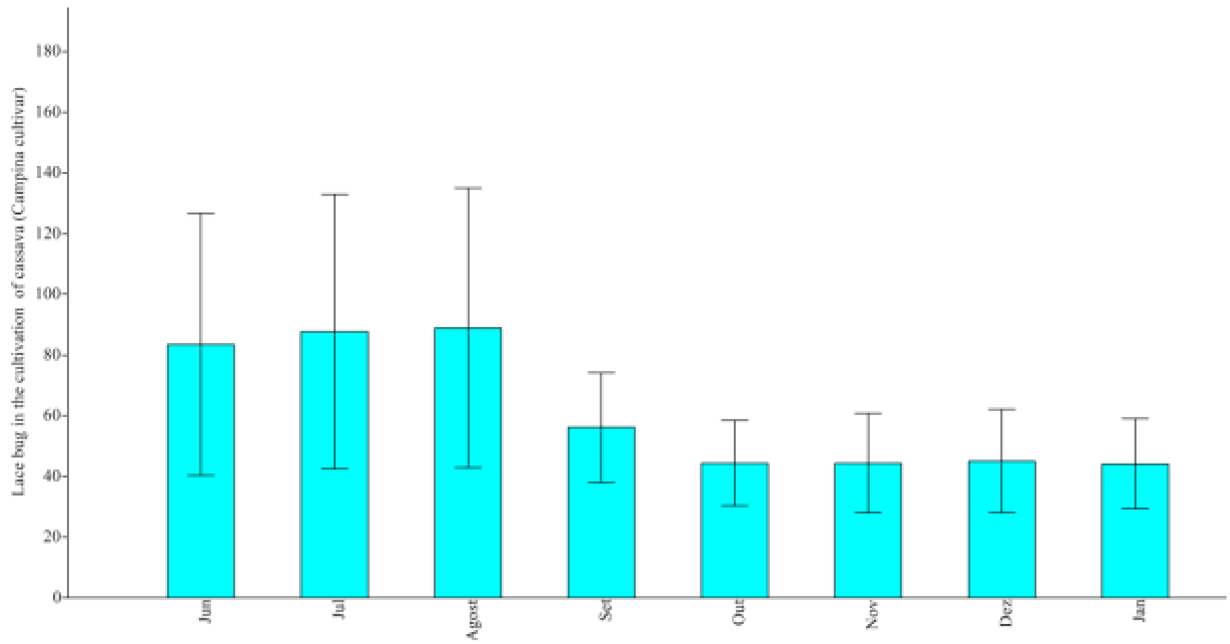

Figure 2. Population monitoring of the income bug during the research (June / 2017-January / 2018) (Campina cultivar). Source: Research data.

months of March, April and May. For the second cycle, the population began to increase in November, reaching its population peaks from December to February and again in April.

Martinazzo et al. (2007) determining the population fluctuations in *V. manihotae*, also reported a higher incidence of these insects in the second cassava cycle. According to these authors, the higher incidence may be related to the formation of a more intense foliar mass in the regrowth of the plant, with greater food availability, allowing the insect to complete a larger number of generations in that period and consequently to increase its population.

Evaluation of the correlations of climatic elements and phenological variables on insect phases

The estimates of correlations between the phenological variables, insect phases and climatic factors in the Campina and Sergipana varieties are shown in Table 2. The data presented for the correlations were significant ($p < 0.01$). The magnitudes are defined as follows: weak ($0.20 < |r| < 0.40$), moderate ($0.40 < |r| < 0.60$) and strong ($0.60 < |r| < 0.80$); these parameters are corroborated by the publication of Franzblau (1958).

Pearson indices in the two correlation matrices, between the biotic and abiotic variables, were within the weak-to-moderate range in the two cassava cultivars. The adult variables and nymphs had negative correlations with the others; the exception was the positive correlation between biotic (nymphs) ($r = 0.15$) and abiotic (precipitation) ($r = 0.24$). If the correlations are positive, the benefits are mutual; however, if one is positive and another is negative, the effects move in opposite directions. For the two cultivars, this phenomenon was observed.

Similar results were obtained by Fialho et al. (2009) who found a negative correlation for *V. illudens* nymphs and adults with cassava root and shoot yield in three years of evaluation. Uemura-Lima (2017) stated that the maximum, average and minimum temperatures positively affected the population of *V. illudens* nymphs (Drake, 1922). It was discovered that the correlation between leaves ($r = 0.66$) and height ($r = 0.63$) of the plant showed higher positive correlations. The temperature and relative humidity of the air are other abiotic factors that influence in the development of the plant and the insects hosted there. They then become limiting in distinct environments in cassava cultivation, a plant that is very sensitive to these variations and may present variable responses (El-sharkawy, 2003; Long, 2006; El-sharkawy et al., 2012).

Uemura-Lima (2017) evaluated the interaction between temperature, relative humidity and precipitation, and observed that the number of eggs of *Vatiga* spp. increased as temperature increases; however, the opposite occurs if the increase is for humidity and precipitation. According to Uemura-Lima (2017), in general, the leaf of the cassava plant is able to withstand damage caused by the lace bug, even at high population numbers, when the insect remains for a short time in the plant, both for cultures in the first and the second cycle. Nevertheless, as the feeding time of the insects increases

Table 2. Pearson's index of linear correlations in cassava cultivars.

Variable	Campina								
	Adults	**Nymphs**	**Height**	**Leaves**	**Stem**	**Branches**	**Rh**	**Temp.**	**Rain.**
Adults	-	-0.41							
Nymphs	-0.30	-							
Height	0.33	-0.00	-						
Leaves	0.66	-0.23	0.63	-					
Stem	0.54	-0.30	0.03	0.41	-				
Branches	-0.36	-0.16	0.25	0.22	0.17	-			
Rh	0.45	-0.51	0.09	0.42	0.00	-0.01	-		
Temp.	-0.23	-0.32	0.70	-0.90	0.56	0.46	0.26	-	
Rain.	0.24	0.15	0.54	0.45	-0.40	-0.55	-0.42	-0.64	-
	Sergipana								
Adults	-	-0.27							
Nymphs	-0.30	-							
Height	0.50	-0.21	-						
Leaves	0.49	0.19	0.73	-					
Stem	0.14	-0.03	0.46	0.73	-				
Branches	0.02	-0.35	0.58	0.47	0.80	-			
Rh	-0.37	0.00	0.28	-0.08	-0.35	-0.09	-		
Temp.	0.23	0.35	0.74	-0.91	0.57	0.38	0.26	-	
Rain.	0.24	0.15	0.54	0.45	-0.40	-0.55	-0.42	-0.64	-

Legend: Rh = Relative humidity. Temp. = temperature and Rain. = rainfall.

in the leaf, the damage increases, regardless of the population present in the leaf.

Fialho et al. (2009) described a decrease of the phenological growth of the plant due to the number of adult and nymph lace bugs, possibly related to the damage that the insect causes to the leaves. The other species *V. illudens*, in the adult and nymph phases, causes damage to the plant (Bellotti et al., 2012). Another form of damage is the drop of the aerial part of the plant, an injury caused by the lace bug that triggers senescence and loss of leaves (Alves and Stter, 2004). Sucking insects reduce the photosynthetic rate in several ways, with reduced stomatal conductance and changes in water transport being the main causes of this reduction (Bellon et al., 2017; Nabity et al., 2009; Zvereva et al., 2010).

It is important to point out that research on population fluctuation of a pest and its relation to climatic factors presents different results from one region to another. That is, a factor that presents significant correlations in one region may not be relevant in another region; suggesting that the fluctuation population is specific to each assessed site (Portela et al., 2010).

Conclusion

Cassava cultivation in protected environments can be influenced by climatic elements, causing lower phenological development of the cultivars that correlated with the presence of lace bugs. The correlations of the climatic elements with the phenological variables on the phases of the lace bug in cassava cultivars grown in a greenhouse indicate that they are related. Further studies of the occurrence and population fluctuations of *V. illudens* in the study region are required.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Comparison of cyanobacterial bio-fertilizer with urea on three crops and two soils of Ethiopia

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Although chemical fertilizers have long been used to meet the high demand of nitrogen (N), the most common limiting nutrient to plant growth, the frequent use of this fertilizer gradually deteriorates soil fertility in addition to its high cost, lower supply and agronomic use efficiency in Ethiopia. Nevertheless, N-fixing cyanobacterial biofertilizers are eco-friendly, and currently considered important to support the developing organic agriculture. Therefore, this study was conducted to evaluate the potential of cyanobacterial biofertilizer for the growth and yield of three commonly growing crops in Ethiopia: maize, kale, and pepper under Alfisol and Andosol, and to investigate the potential contribution of cyanobacteria biofertilizer in selected soil fertility parameters. Three independent factorial experiments were conducted simultaneously in the greenhouse. Each experiment included a factorial combination of four nitrogen fertilizer sources applied at recommendation rate for each crop (control, urea, dried cyanobacteria, and liquid cyanobacteria,) and two soil types with acidic and alkaline pH (Alfisols and Andosols, respectively) arranged in a complete randomized design (CRD) with three replications. Application of dried and liquid cyanobacterial biofertilizer treatments significantly improves the soil N, soil organic carbon (SOC) and available P, Fe and Zn. Cyanobacteria treatments were also found to reduce or maintain the mean soil pH. Accordingly, maximum values of all the vegetative growth attributes of kale, and maize were obtained from the application of two comparable-fertilizer treatments: air-dried cyanobacteria and urea while for pepper crops only dried cyanobacteria. Concentrations of N, P, Zn, and Fe in leaves of kale, pepper, and maize were also significantly increased by air-dried cyanobacterial biofertilizer. Overall, dried cyanobacteria improved the growth and yield of the three crops, and the fertility of the soils. Therefore, the use of dry cyanobacterial biofertilizer could be recommended as a supplementary N source to inorganic fertilizer for kale, pepper and maize production in both study sites.

Key words: Alfisols, andosols, biofertilizers, cyanobacteria, N-fixing.

INTRODUCTION

Nutrient depletion is one of the major causes that contribute to decline in soil productivity in Ethiopia; soils under subsistence agriculture have been mined of nutrients for years without replenishment with fertilizer inputs in the country. Hence, the two essential plant nutrients, N and P are the most limiting nutrients nearly in all agricultural soils of Ethiopia (Paulos, 2001; Wassie et al., 2006). On average, N and P depletion rates in Ethiopian soil exceed 40 and 6 kg ha^{-1} yr^{-1}, respectively (Stoorvogel and Smaling, 1990; Smaling et al., 1997).

One way of improving soil fertility is the use of inorganic fertilizers. Adugna and Hiruy (1988) reported that majority of Ethiopian soils gave high response to applied nitrogen. Nevertheless, the use of this input among smallholder farmers is currently very low in the country. High fertilizer costs, marketing problems and poor infrastructures are some of the major reasons for low use of fertilizers in Ethiopia (Schneider and Anderson, 2010; Girma et al., 2016). Moreover, synthetic N fertilizers have lower agronomic use efficiency due to losses of applied N through volatilization, leaching and denitrification (Havlin et al., 2010); as a result, higher amount of chemical N fertilizers is applied to meet the crop demand. Excess use of chemical fertilizers may result in multi-nutrient deficiencies and nutrient imbalance in soil. Furthermore, it also generates several environmental problems including acidification of water (Choudhury and Kennedy, 2005). Therefore the use of other alternative options of soil fertility replenishment is indispensable to maintain soil fertility and productivity (Girma et al., 2016; Wassie et al*.,* 2006).

Biofertilizers, being essential components of organic farming, play key role in maintaining long term soil fertility and sustainability by fixing atmospheric dinitrogen (N=N), mobilizing fixed macro and micronutrients or converting insoluble phosphate present in the soil into forms available to plants, thereby increasing their use efficiency and availability (Sahu et al*.,* 2012). They are cost effective, ecofriendly and a renewable source of plant nutrients to supplement chemical fertilizers (Aref et al., 2009). Thus, the possibility of using biofertilizers as an alternative or a complementary for mineral fertilization has been the focus of researchers (Prasanna et al*.,* 2012). Cyanobacteria as a biofertilizer can decrease the demand for mineral form of N fertilizers. They are photosynthetic prokaryotic microorganisms capable of fixing atmospheric N_2 using sunlight as the sole energy source. They are free-living as well as symbiotic. Some filamentous cyanobacteria exhibit cellular differentiation to produce heterocysts; highly specialized cells that fix atmospheric nitrogen (Hegazi et al*.,* 2010; Kulasooriya, 2011). The dominant nitrogen fixing cyanobacteria are *Anabaena, Nostoc, Aulosira, Calothrix* and *Plectonema* (Sahu et al*.,* 2012).

Cyanobacteria have been widely employed as inoculants for enhancing soil fertility and improving soil structure in addition to enhancing crop yield. They are a cheap source of N, which does not cause pollution and quite suitable for resource poor smallholder farmers (Kulasooriya, 2011). Beneficial effects of cyanobacteria inoculation were reported on rice, barley, oats, tomato, radish, cotton, sugarcane, chilli and lettuce (Thajuddin and Subramanian, 2005). In a similar scenario, Prasanna et al*.* (2009) reported that inoculation of *Calothrix* as a biofertilizer shows an increase of 21% in grain yield of rice over the recommended NPK. In addition, the possibility of reducing Fe and Zn malnutrition in developing countries through cyanobacteria biofertilizer has been reported (Rana et al*.,* 2012). Cyanobacteria also change the physical, chemical and biological properties of the soil. Inoculation of soil with *Nostoc muscorum* led to a pronounced effect on soil chemical properties, with total carbon increasing by 56 % and total N increasing by 120% of the initial (Rogers and Burns, 1994). Many cyanobacteria have also been shown to mobilize the insoluble phosphate in the soil, thereby increasing their availability to the crop plants, provide oxygen to the submerged rhizosphere, ameliorate salinity, buffer the pH and increase the efficiency of fertilizer use in crop plants (Kaushik, 2004). Besides, many researchers demonstrated increase in availability of Fe and Zn content of the soil through cyanobacteria biofertilization (Belnap and Harper, 1995; Puste and Das, 2002).

Despite the fact that many experiments had been conducted on cyanobacteria biofertilizer, research findings were contradicting each other when it comes to the method of application. Moreover, scanty information was available in Ethiopia on the potential of this biofertilizer in the growth of maize, kale and pepper, under Alfisols and Andosols soils which represent the major soil portion in the study areas. The objectives of the present study were; therefore, to study the effect of cyanobacterial biofertilizer application on growth and yields of three commonly growing crops in the study areas: maize, kale and pepper and to investigate the potential contribution of cyanobacteria biofertilizer to selected soil fertility parameters. The expected result could identify the best cyanobacterial bio-fertilizer management practices for kale, maize and pepper growth and for soil fertility improvement at greenhouse level.

MATERIALS AND METHODS

Three independent experiments were carried out simultaneously on

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Table 1. Plant varieties, fertilizer application rates, and harvest age for greenhouse experiments on kale, hot pepper, and maize.

Variety	Kale	Hot pepper	Maize
	Yellow Dodolla	MarekoFana	Gibe II
N Rate (kg N/ha)	100	100	64
P Rate (kg P/ha)	30	40	20
Harvest Age (d)	50	58	45

Table 2. Physico-chemical characteristics of the surface of Alfisols and Andosols prior to treatment application.

Soil characteristics	Alfisols	Andosols
Textural class	Clay	Clay Loam
Organic carbon (%)	1.7	2.4
Cation Exchange Capacity (cmol(+) kg^{-1})	21.5	40.4
Field Capacity (%)	38	30
Permanent Wilting Point (%)	30	18
pH in water (1:2.5)	5.8	8.1
EC (mS cm^{-1})	0.11	0.27
Total N (%)	0.19	0.22
Av. P (mg kg^{-1})	8.0	15.0
Exch. K (cmol(+) kg^{-1})	1.3	2.1
Av. Zn (mg kg^{-1})	6.2	2.4
Av. Fe (mg kg^{-1})	10.7	1.6

kale (*Brassica carinata* L.), hot pepper (*Capsicum annuum* L.), and maize (*Zea mays* L.) in a greenhouse at Hawassa University, Hawassa, Ethiopia (Table 1). Each experiment included a factorial combination of four nitrogen fertilizer sources applied at recommended rate for each crop (control, urea, dried cyanobacteria, and liquid cyanobacteria,) and two soil types (Alfisols and Andosols) arranged in a complete randomized design (CRD) with three replications. The soils samples were collected from Ziway and Yirgalem Southern part of Ethiopia. The coordinates of the two locations were 07° 58' 6.7" N and 38° 23' 20.9" E and 06° 44' 57.5" N and 38° 23' 26" E, respectively. The soils at Ziway and Yirgalem area represented a tropical Andosols (pH 8.0) and typical tropical Alfisols (pH 5.7), respectively (Girma et al*.,* 2012).

Soils were collected from a depth of 0 to 20 cm, air dried, and sieved to pass through a 5 mm sieve. Triple super phosphate (TSP) was mixed with soil prior to sowing at recommended rates for each crop. Pots were 20 cm in diameter and 18 cm deep, and each pot was filled with 4 kg soil (12 cm deep). Five seeds were sown per pot and thinned to two plants after establishment. Weeds were removed weekly, and pots were watered up to field capacity every other day. Following each watering, any leachate captured on saucers was reapplied to the pots.

Soil samples were air dried and ground to pass through a 2 mm sieve for all analyses except soil organic carbon (SOC) and total nitrogen (TN), for which soil samples were further passed through a 0.5 mm sieve. The soil samples were analyzed for soil texture by the hydrometer method (Bouyoucos, 1962), OC by dichromate oxidation (Walkley and Black, 1934), cation exchange capacity (CEC) by the 1M ammonium acetate method at pH 7 (Chapman, 1965), moisture content at field capacity (-1/3 bar) and permanent wilting point (-15 bars) using pressure plate extraction (Klute, 1965), pH in a soil: water ratio of 1:2.5 (Van Reeuwijk, 1992), electrical conductivity (EC) in a 1:2.5 soil:water ratio soaked for one hour (Sertsu and Bekele, 2000), N by the micro Kjeldahl method (Bremner and Mulvaney, 1982), available P extracted with $NaHCO_3$ (Olsen et al.,1954), exchangeable K by NH_4OAc extraction (Chapman, 1965), and available Zn and Fe by DTPA extraction (Lindsay and Norvell, 1978) (Table 2).

Anabaena sp. strain E-3 was cultured from local soil samples using Allen-Arnon media (Allen and Arnon, 1955) and grown under cool white fluorescent lights (2500 lux) with bi-weekly transfers. Then large quantities were grown in Allen-Arnon media in aerated 1 × 2 m ponds with a 0.2 m depth (filled to 0.15 m and lined with transparent polyethylene sheeting) under plastic (transparent plastic painted white) inside a hoop house on the Hawassa University. The ponds were seeded with 20 L of Allen-Arnon based *Anabaena* sp. strain E-3 and filled up to 300 L with Allen-Arnon media. The daytime air temperature in the hoop house ranged from 27 to 38°C, and light intensity ranged from 5700 to 7700 lux. Cyanobacteria were harvested after 21 d of growth and utilized as either liquid (42 mg N L^{-1}) or air-dried (3.0% N) fertilizers.

All fertilizers were applied at the same N rates within each study based on crop-specific N recommendations from the government of Ethiopia (Table 1). An air-dried and ground to pass through a 2 mm sieve cyanobacterialbiomass was incorporated into pots nominated for this application one week prior to seed sowing for kale and hot pepper and 15 days before sowing for maize, and water was appliedup to field capacity to allow time for decomposition. The liquid cyanobacterial culture was split into three applications (the first third one to two weeksprior to sowing, and other splits thereafter in seven to 10 d intervals) to avoid overwatering and was uniformly poured into each pot. Other treatments received equal amounts of water in order to keep this variable constant across treatments. Urea was applied prior to sowing for maize and half prior to sowing and half 20 d later for hot pepper and kale.

Measurements

Plant parameters were measured at end of the experiments (Table 2). Plant height was measured as the length from the soil surface to the apical bud of kale, to the uppermost growth of pepper (at the blooming stage) and maize (at the end of the experiment). The average height of the two plants in each pot was taken on the day of harvest. The leaf number was counted on the harvest date for kale and maize, and the number of primary branches was counted for hot pepper. The total leaf area was recorded from each plant using a leaf area meter (Li-cor 3100), and average per plant was calculated for each pot. Plant biomass was harvested, and root and shoot parts were separated and dried in an oven at 60 to 70°C for 48 h or more to a constant weight, and final weights were recorded.

Leaf samples were taken at harvest (all leaves for kale and maize, and most recently matured leaves of hot pepper), oven dried as described above and ground. N was analyzed by modified Kjeldahl procedure (Nelson, 1980). One gram of plant material (dried at 105°C for 24 h) was calculated in a muffle furnace at 450°C, dissolved in 20% nitric acid, and filtered. Extracts were analyzed for P, Zn, and Fe contents by colorimetric analysis (Wolf, 1982), andatomic absorption spectroscopy (Isaac and Kerber, 1971), respectively. After harvest, soil samples were taken from the entire 12 cm soil depth, air-dried, sieved, and analyzed for pH, SOC, Kjeldahl N, and available P, Zn, and Fe following standard laboratory procedures.

Statistical analysis

Data were subjected to analysis of variance (ANOVA) using general linear models (Proc GLM) of the statistical analysis system (SAS Institute, 2003). Whenever significant differences were detected in the F- test, the means were compared using the least significant difference (LSD) test at the 5% significance level. Correlation analysis was conducted between relevant parameters using Pearson’s correlation test.

RESULTS AND DISCUSSION

Soil properties

Cyanobacterial bio-fertilizer reduced soil pH in all three trials (Table 3). This might be due to the fact that, as the cyanobacteria decompose, they release organic acids, and the nitrification process also releases H^+ ions, thus leading to the reduction in soil pH. The urea treatment was moderate in pH between the control and cyanobacteria treatments. Interestingly, in the maize study there was a significant interaction between fertilizer source and soil type for soil pH, SOC, and available P (Table 4). The pH reduction was 0.5 units in the alkaline soil (Andosols) but only 0.2 units in the acidic soil (Alfisols), resulting in soil pH levels of 7.5 and 5.5, respectively. The result was in agreement with the finding of Dasappa et al. (2004) who reported a reduction of soil pH from 8.4 to 7.0 in cyanobacteria treated pots on Mulberry. This was also in conformity with the study of Amal et al. (2010) who found that soil pH was slightly decreased by inoculation with cyanobacteria in the first season, while, the second season revealed a significant reduction in these parameters particularly when the combined application of seed coating and soil drench was applied with 75% N.

The cyanobacterial bio-fertilizer treatments, applied in either dry or liquid form, consistently increased SOC, which was expected (Table 4). The urea also affected SOC, although the impact was inconsistent, decreasing it in the kale experiment, increasing it in maize, and having no effect in pepper. This could be due to carbon fixation capacity of cyanobacteria as they are photoautotrophic in nature. The observed increase in soil organic carbon was comparable with the finding of Maqubela et al. (2009). The observed increases in soil SOC were comparable to those reported by Dasappa (2004) and Christopher et al. (2009) in a similar study.

Although urea and the cyanobacterial bio-fertilizer treatments were applied at the same N rate, the total N concentration in the soil was higher at the end of the experiments in the cyanobacterial treatments as compared to urea, with the exception of the liquid cyanobacteria applied to hot pepper (Table 3). This could be due to higher volatilization of NH_3 and N_2O from urea or increased N fixation by the cyanobacteria; however, continued N fixation was doubtful in the dry cyanobacterial treatment due to the drying and grinding process that was used to prepare this fertilizer. Christopher et al. (2009) forwarded the reason for higher concentration of total N in the soil after cyanobacteria inoculation that the slow release and lower lose of nutrients in the case of application of this biofertilizer. The increase in total soil N due to the applied nitrogen-fixing biofertilizer was also noted by Kemka et al. (2007).

In addition, soil available P, Zn, and Fe were all increased in the cyanobacterial bio-fertilizer treatments, while the urea treatment was equivalent to the control (Table 3). This is not surprising since P, Zn, and Fe are all supplied in the Allen-Arnon media to optimize the growth of the cyanobacteria. In the maize study, the impact on available P was only significant in the alkaline soil (Andosols) (Table 4). The possible reason for this is that cyanobacterial biofertilizer has the ability to dissolve and complex with those ions (Fe and Zn), making them more available in the soil (Kemka et al., 2007). Similarly, Aref et al. (2009) and Hegazi et al. (2010) also reported a significant increase in P availability of alkaline soil due to the application of cyanobacteria biofertilizers.

Plant growth parameters

The dry cyanobacteria application resulted in the greatest plant height and shoot dry weight for all three plant species tested (Table 5). The plant height and shoot weight in the urea treatment was equivalent to that of the dry cyanobacteria treatment in kale and maize, but the

Table 3. Impact of N fertilizer sources on soil pH, OC, Kjeldahl N, and available P, Zn, and Fe concentrations.

Fertilizer source	pH	OC	N	Available P	Available Zn	Available Fe
		--%--	--%--	--mg kg^{-1}--	--mg kg^{-1}--	--mg kg^{-1}--
				Kale		
Control	7.0^{a†}	2.2^{b}	0.15^{c}	29.7^{c}	5.8^{c}	2.8^{c}
Urea	6.8^{ab}	2.1^{c}	0.23^{b}	24.2^{c}	5.9^{c}	2.4^{c}
Dry Cyanobacteria	6.4^{c}	2.4^{a}	0.27^{a}	54.4^{a}	10.2^{a}	5.8^{a}
Liquid Cyanobacteria	6.5^{bc}	2.4^{a}	0.26^{a}	41.0^{a}	7.2^{b}	4.5^{b}
				Hot pepper		
Control	7.1^{a}	2.0^{c}	0.15^{c}	30.9^{c}	3.9^{c}	3.1^{b}
Urea	6.9^{ab}	1.9^{c}	0.25^{b}	29.0^{c}	3.8^{c}	2.8^{b}
Dry Cyanobacteria	6.6^{c}	5.1^{a}	0.33^{a}	74.4^{a}	8.7^{a}	6.4^{a}
Liquid Cyanobacteria	6.8^{b}	3.7^{b}	0.27^{b}	66.1^{b}	7.5^{b}	5.3^{a}
				Maize		
Control	6.8^{a}	2.3^{d}	0.20^{c}	8.7^{c}	4.8^{b}	10.8^{b}
Urea	6.7^{b}	2.5^{c}	0.22^{b}	8.8^{c}	4.8^{b}	11.1^{b}
Dry Cyanobacteria	6.5^{c}	2.8^{b}	0.24^{a}	11.0^{b}	6.1^{a}	12.2^{a}
Liquid Cyanobacteria	6.5^{c}	3.0^{a}	0.24^{a}	11.9^{a}	6.3^{a}	11.9^{a}

†Means followed by a common letter within crop and nutrient are not significantly different based on Least Significant Differences at $p \leq 0.05$.

Table 4. Interactions between fertilizer source and soil type in soil pH, OC, and available P in a maize greenhouse study.

Fertilizer Source	pH		OC		Available P	
Soil Type	**Alfisols**	**Andosols**	**Alfisols**	**Andosols**	**Alfisols**	**Andosols**
			----%----		----mg kg^{-1}----	
Control	5.7^{a†}	8.0^{a}	2.2^{d}	2.4^{c}	2.3^{a}	15.0^{c}
Urea	5.6^{ab}	7.8^{a}	2.3^{c}	2.6^{b}	2.5^{a}	15.1^{c}
Dry Cyanobacteria	5.5^{ab}	7.5^{b}	2.7^{b}	3.0^{a}	2.7^{a}	19.2^{b}
Liquid Cyanobacteria	5.5^{b}	7.5^{b}	2.9^{a}	3.0^{a}	3.0^{a}	20.9^{a}

†Means followed by a common letter within column are not significantly different based on Least Significant Differences at $p \leq 0.05$.

liquid cyanobacteria resulted in shorter plants with less mass (although they were greater than the control). The root dry weights showed a similar pattern to shoot dry weight in kale and pepper, but in maize, the urea and cyanobacterial treatments were not different in root dry weight. These results are in agreement with Amal et al. (2010) who found out that the morphological characters and performance of bean in terms of plant height, was enhanced by cyanobacteria application. Similarly, Bhuvaneshwari et al. (2011) reported that cyanospray applied, 0.5% cyanospray treated plants showed better results on all the morphological parameters such plant height and dry weight of shoot.

The leaf number and area were also significantly impacted by the fertilizer treatments (Table 5). In maize and pepper, the dry cyanobacteria resulted in the greatest leaf number and branch number, respectively, and urea and liquid cyanobacteria were intermediate between the control and dry cyanobacterial treatments. In kale, the leaf number in the urea treatment was equivalent to that of the dry cyanobacteria. The leaf area was consistently highest in the dry cyanobacterial treatment, with urea having an equivalent leaf area in kale and maize, but a significantly lower leaf area in pepper. The more leaf number and area per plant in kale and maize obtained in treatments receiving cyanobacteria was probably due to its better capacity to supply N and other nutrients to the plant during its growth (Mahmoud et al., 2007). This result was consistent with the finding of Amal et al. (2010) who reported the significant increase in

Table 5. Impact of N fertilizer sources on plant growth characteristics of kale, hot pepper, and maize.

Fertilizer source	Plant height (cm)	Leaf number†	Leaf area (cm^2 $plant^{-1}$)	Shoot dry weight (g $plant^{-1}$)	Root dry weight (g $plant^{-1}$)
			Kale		
Control	29.2[c‡]	9.2[c]	261[c]	2.0[c]	0.4[c]
Urea	38.5[a]	12.8[a]	629[a]	4.3[a]	0.9[a]
Dry Cyanobacteria	40.0[a]	12.3[a]	648[a]	4.4[a]	1.0[a]
Liquid Cyanobacteria	34.9[b]	11.4[b]	388[b]	3.2[b]	0.6[b]
			Hot pepper		
Control	13.3[c]	2.8[c]	161[c]	5.1[c]	0.9[c]
Urea	18.0[b]	5.5[b]	327[b]	8.3[b]	2.0[b]
Dry Cyanobacteria	22.7[a]	8.9[a]	405[a]	14.0[a]	3.0[a]
Liquid Cyanobacteria	18.8[b]	5.8[b]	332[b]	9.5[b]	2.2[b]
			Maize		
Control	32.4[c]	3.8[c]	269[c]	1.2[c]	0.9[b]
Urea	41.5[ab]	5.1[b]	526[a]	2.6[a]	1.6[a]
Dry Cyanobacteria	45.0[a]	5.8[a]	540[a]	2.8[a]	1.5[a]
Liquid Cyanobacteria	39.9[b]	5.0[b]	408[b]	2.3[b]	1.6[a]

†Branch number is reported for hot pepper.
‡Means followed by a common letter within crop and nutrient are not significantly different based on Least Significant Differences at $p \leq 0.05$.

number of leaves and area of common bean by the application of dried and fresh cyanobacterial bio-fertilizer. In addition, Bhuvaneshwari et al. (2011) find out that incorporation of Cyanobacterial Bio-fertilizer increased number of leaves and area of Sunflower. Krishna et al. (2012) also revealed that cyanobacterial bio-fertilizer of cyanopith and cyanospray applications have significantly increased the leaf width of *Aloe vera* crop when compared to control.

In general, the plants receiving dry cyanobacteria grew better than those fertilized with liquid cyanobacteria. This may be due to the drying and grinding process resulting in quicker N mineralization from the dry cyanobacteria. In the liquid cyanobacterial treatments, green growth was visible around the pot edges, demonstrating that the liquid cyanobacterial fertilizer did not completely die and release its nutrients for plant uptake, but continued to live throughout the experimental duration. The dry cyanobacterial bio-fertilizer, generally, increased plant growth compared to urea, as well, even though they were applied at the same N rate. This may be due to the presence of other plant nutrients in the cyanobacterial bio-fertilizer. We had applied TSP at equivalent rates across the fertilizer treatments to avoid interference due to differential P levels, and the soils did not seem to require any additional nutrients (Table 2). Alternatively, this difference could be due to higher N volatilization losses from the urea treatment; unfortunately, this parameter was not measured.

Plant nutrient concentrations

All fertilizer treatments increased plant N concentrations as compared to the control (Table 6). The dry cyanobacterial bio-fertilizer resulted in the highest plant N concentrations in all three crops, although urea resulted in equivalent plant N levels in kale and maize. Nitrogen concentrations in plants receiving liquid cyanobacteria were higher than control but usually lower than urea.

Plant N was highly significantly ($p<0.001$) correlated with soil N in kale and hot pepper, but this correlation was not significant in maize. Both soil N and plant N concentrations were significantly correlated with plant height, leaf number, leaf area, shoot dry weight, and root dry weight for all three crops (Table 7). In general, the correlations were stronger with plant N than with soil N. Both the dry and liquid cyanobacterial bio-fertilizers increased plant P, Zn, and Fe concentrations in kale, pepper, and maize (Table 6). This could be due partly to the presence of these nutrients in the Allen-Arnon nutrient media used to produce the cyanobacterial bio-fertilizer. Moreover, cyanobacteria are known to increase the availability of P in the rhizosphere, which facilitate its transport to the root and provide P to the crop, and consequently increase tissue P concentration (Prasanna et al., 2012). Dried cyanobacteria increased N status of crops over the control; this may positively influence the mobility and root uptake of Zn and Fe from the soil (Cakmak et al., 2010). The expression level of Zn and Fe

Table 6. Impact of N fertilizer sources on N, P, Zn, and Fe concentrations in leaves of kale, hot pepper, and maize.

Fertilizer source	N	P	Zn	Fe
	--%--	--%--	--mg kg^{-1}--	--mg kg^{-1}--
		Kale		
Control	4.16^{c†}	0.29^{c}	38^{d}	92^{c}
Urea	6.14^{a}	0.56^{a}	83^{b}	126^{b}
Dry Cyanobacteria	6.47^{a}	0.58^{a}	104^{a}	154^{a}
Liquid Cyanobacteria	5.46^{b}	0.42^{b}	62^{c}	120^{b}
		Hot pepper		
Control	2.39^{c}	0.37^{b}	53^{b}	88^{d}
Urea	4.33^{b}	0.41^{b}	60^{b}	102^{c}
Dry Cyanobacteria	5.25^{a}	0.60^{a}	156^{a}	166^{a}
Liquid Cyanobacteria	4.55^{b}	0.56^{a}	140^{a}	142^{b}
		Maize		
Control	2.16^{c}	0.24^{c}	35^{d}	89^{c}
Urea	4.14^{a}	0.54^{a}	59^{c}	123^{b}
Dry Cyanobacteria	4.47^{a}	0.52^{a}	101^{a}	151^{a}
Liquid Cyanobacteria	3.46^{b}	0.37^{b}	80^{b}	117^{b}

†Means followed by a common letter within crop and nutrient are not significantly different based on Least Significant Differences at p≤0.05.

Table 7. Correlation coefficients among soil and plant characteristics in kale, hot pepper, and maize greenhouse trials.

Correlations	Kale	Hot pepper	Maize
Soil pH vs. Soil N	0.03	0.11	0.72***
Soil pH vs. Soil P	0.17	-0.02	0.93***
Soil pH vs. Soil Zn	-0.85***	-0.78***	-0.92***
Soil pH vs. Soil Fe	-0.90***	-0.86***	-0.99***
Soil pH vs. Plant N	-0.18	-0.14	-0.04
Soil pH vs. Plant P	-0.09	-0.07	-0.06
Soil pH vs. Plant Zn	-0.37	-0.73***	-0.34
Soil pH vs. Plant Fe	-0.43*	-0.68***	-0.41*
Soil N vs. Plant N	0.69***	0.93***	0.36
Soil P vs. Plant P	0.10	0.92***	0.04
Soil Zn vs. Plant Zn	0.56**	0.98***	0.45*
Soil Fe vs. Plant Fe	0.62**	0.87***	0.42*
Soil N vs. Plant Height	0.64***	0.54**	0.68***
Soil N vs. Leaf Number‡	0.63***	0.47*	0.53**
Soil N vs. Leaf Area	0.46*	0.42*	0.42*
Soil N vs. Shoot Dry Weight	0.62**	0.43*	0.83***
Soil N vs. Root Dry Weight	0.48*	0.45*	0.61**
Plant N vs. Plant Height	0.76***	0.72***	0.66***
Plant N vs. Leaf Number	0.85***	0.65***	0.88***
Plant N vs. Leaf Area	0.82***	0.65***	0.91***
Plant N vs. Shoot Dry Weight	0.86***	0.62***	0.71***
Plant N vs. Root Dry Weight	0.84***	0.69***	0.66***

†*,**,*** significantly different at p ≤0.05, 0.01, and 0.001 respectively.
‡Branch number was utilized in place of leaf number for hot pepper.

transporter proteins located on the root cell membrane increased by the plant N status and these proteins enhance uptake and accumulation Zn and Fe in the plant tissue (Rana et al., 2012).

However, the urea fertilizer also increased plant P, Zn, and Fe concentrations in kale and maize and Fe in hot pepper. This was apparently due to the soil pH reduction caused by urea application. Since the cyanobacterial bio-fertilizers also reduced soil pH, this reduction may also contribute to increased plant P, Zn, and Fe measured in those treatments. Soil pH was highly significantly ($p<0.001$) negatively correlated with available soil Zn and Fe for all three crops, as expected (Table 7). Soil pH was also significantly negatively correlated with plant Fe concentrations for all three crops, but pH was only significantly correlated with plant Zn for hot pepper.

The relationship between soil pH and P availability is more complicated since P availability is optimum in near neutral pH. Therefore, we would expect that in acid soil, there would be a positive correlation between pH and available P, but the opposite would be true in alkaline soils. Soil pH was only significantly correlated with available soil P in maize and was not significantly correlated with plant P in any crop (Table 7). Soil P and plant P concentrations were only significantly correlated in hot pepper.

Conclusion

Application of dried cyanobacteria led to increase in growth and yield of maize pepper and kale, and fertility of both soils. Dried cyanobacterial bio-fertilizer also improved nutritional qualities of the three crops by increasing micronutrient (Zn and Fe) concentration especially in the edible parts of kale and pepper. This will have a paramount importance in alleviating the problem of zinc deficiency among pregnant women and children in Ethiopia. Hence, production and selling of dry cyanobacteria biofertilizer locally could have a positive impact on food and nutritional security in Ethiopia.

Moreover, cyanobacterial bio-fertilizer also consistently increased soil organic carbon sequestration and improved organic carbon stock in the soil, and this has important soil quality implications for Ethiopia's degraded soils. Overall, the use of dry cyanobacteria will reduce application of urea in agricultural land. Reducing imported urea and supplementing with locally-produced cyanobacterial bio-fertilizer could reduce CO_2 emissions from fertilizer production and transportation while also enhancing carbon sequestration.

In addition, volatilization losses of NH_3 and N_2O have yet to be measured and compared to commonly used fertilizers. Collecting these data may help to explain the increased soil N values in these greenhouse studies. Therefore, additional research should be carried out to evaluate the impact of cyanobacterial bio-fertilizer on soil pH, soil quality, carbon sequestration, and NH_3 and greenhouse gas emissions.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Genetic variation and heritability of kernel physical quality traits and their association with selected agronomic traits in groundnut (*Arachis hypogeae*) genotypes from Uganda

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Breeding for improvement of physical kernel traits has a direct implication on acceptance of groundnut varieties. However, the genetic parameters associated with these traits are not well documented. Ten groundnut lines were evaluated in a Randomized Complete Block Design experiment with three replicates in 2015. Data were collected on yield parameters and pod and kernel physical traits. Mean values were used to determine the characters' phenotypic, genotypic, environmental variances, phenotypic and genotypic coefficients of variation. Broad sense heritability and genetic advance as a percentage of mean were estimated for each trait. Significant variation existed in most traits. The coefficients of variation were low for all traits (<50%), except for hundred seed weight and pod numbers/plot, implying a low environmental influence, and ease of selection. Heritability was greater than 80% for most traits whereas genetic advance as percentage of the mean ranged from low in shelling percentage (15%) to high in hundred seed weight (>80%). Dry pod weight was positively correlated with pod and seed size traits. High broad sense heritability and high genetic advance for kernel physical quality traits showed the role of additive genes in the control of these traits, and thus the possibility for indirect selection for yield traits.

Key words: Correlation, genotype, inheritance, pod size, seed size.

INTRODUCTION

The cultivated groundnut (*Arachis hypogaea* L.) is one of the most important legume cash crops grown for use as food and oil (Birthal et al., 2010). Though a native of South America, the crop is grown in over 100 countries around the world. Covering an area of 23.95 million hectares with a production estimated at 36.45 million

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tonnes and an average productivity of 1520 kg/ha. Around 90% of the total production is concentrated in developing countries located in the semi-arid tropics with India and China contributing close to 50% of global output. In Africa, major produces include Nigeria, Senegal, and Sudan. In Uganda, the crop is the second most important legume after common beans (*Phaseolus vulgaris* L.) (Okello et al., 2013), and is produced mainly in the eastern and northern semi-arid dry regions of Uganda (Ronner and Giller, 2012). It is a non-animal source of protein, and used as cash and food crop. In addition, groundnut is grown by small holder farmers with little or no inputs (Mugisha et al., 2011; Mugisha et al., 2014). In the last decade, there has been a noticeable increase in the acreage devoted to the groundnuts in Uganda; however, the productivity of the crop has almost stagnated in the same period (FAOSTAT, 2012), while demand for the crop as a source of food is on the increase. Genetic improvement of the crop remains the most feasible option given the groundnut production landscape in Uganda.

Genetic improvement of a crop depends on the power of genetic diversity within the crop species. Adequate variability improves the possibility for selections and hybridization. The genotypic and phenotypic coefficient variation is helpful in exploring the nature of variability in the breeding population (Acquaah, 2012). Genotypic correlations have been used as an effective tool to determine the relationships among agronomic traits in genetically diverse population for enhanced progress in crop improvement (Bello et al., 2006). Binodh et al. (2008) confirmed that information on character association in crops is important for effective and rapid selection in crop improvement. In addition, the estimate of heritability provides an indication of transmissibility of characters.

Heritability measures the proportion of phenotypic variance which is heritable (Acquaah, 2012). Estimate of heritability provides power to breeders to allocate resources necessary to effectively select for desired traits and to efficiently achieve maximum genetic gain (Smalley et al., 2004). There are different ways to estimate heritability. It may be estimated as broad-sense or narrow-sense, on single plant, individual plot or the mean of entry (Nyquist, 1991 cited in Ogunniyan and Olakajo, 2014). Genetic advance explains the degree of gain obtained in a character under a particular selection pressure. High genetic advance coupled with high heritability estimates offers the most suitable condition for selection. It also indicates the presence of additive genes in the trait and further suggests reliable crop improvement through selection of such traits. Estimates of heritability with genetic advance are more reliable and meaningful than individual consideration of these parameters (Shukla et al., 2006; Nwangburuka and Denton, 2012).

Continuous improvement of groundnut is imperative for the increased competitiveness of the crop. This can be achieved through effective selection of suitable parental materials of significant genetic variability. The objective of the present study is to estimate the genetic variation, genetic associations, heritability and expected genetic advance for kernel physical and selected agronomic traits in the commonly grown groundnut varieties in Uganda and to evaluate suitable selection criteria for further yield improvement.

MATERIALS AND METHODS

Study areas and their characteristics

This study was conducted in the first season of 2015 in four purposefully selected districts of Uganda, representing the major groundnut growing regions of Uganda. These districts include: Hoima, Masindi, Lira, and Kumi. These districts also represent different ethnic communities and agro-ecological zones (AEZ). In the western zone, trials were hosted in Masindi District (Pakanyi sub county, Labong village) and Hoima District (Bugambe sub county, Mairirwe village). This area is predominantly inhabited by the Bantu speaking Banyoro ethnic group. This area receives two rainfall peaks (1200 to 2000 mm), April/May and August/September, respectively. The average annual temperature for this area is 22.9°C. The major economic activity in this area is agriculture with much prominence given to food crops. Lira District is part of the Lango sub region in Northern Uganda. In this district, the trials were hosted in Adek'Okwok sub county, Barr-opuu village. The majority of the population are ethnic Langi and the predominant language is Luo. This region has got a diversified and vibrant economy. The region receives between 1000 to 1400 mm of rainfall annually in a bimodal rainfall pattern - from March to May and again from August to October. The average annual temperature range for this area is 23.6°C. Kumi District is part of the Teso sub-region. It is home to Iteso and Kumam ethnicities. This region receives annual rainfall of about 1100 to 1200 mm, distributed between two seasons of March to May and September to November. Late February/early March is usually the long dry season period while Mid-June to late July is the short one with an annual average temperature of 24°C. In this district, trials were hosted in Atutur sub-county, Kellim village. All the trial sites in each district were selected with the help of local agricultural extension staff.

Genotypes, experimental design and crop management

A total of ten popular (landraces and improved) groundnut varieties were used in this study (Table 1). These were planted out on farmers' fields in each of the four districts. In each district, one central location was identified to host the trial. The trial was set up as randomized complete block design (RCBD) with 3 replications. In each location, blocking was done with respect to direction of variation in the field. In case of a slope, blocks and plots were set perpendicular to the slope direction. In other cases, where there were no obvious slopes, blocking was generally carried out to minimise the within and between plot variation in the field. In each location, treatments were assigned to plots randomly and independently for each block. Single groundnut seeds were planted in 4 row, 2 m– long plots with 45 cm inter row, and at 15 cm between planting stations, respectively. All trials were managed by farmers. No fertilisers or other agrochemicals were applied.

Data collection

Yield data were collected on plot basis. Data were recorded from

Table 1. Cultivar name, source, and attributes of the popular groundnut variety lines in Uganda.

Cultivar name	Source	Attribute
Oluk-oluk-arema	Farmers	Medium, red seed colour
Etesot	Farmers	Medium, Tan seed colour
Gambia	Farmers	Medium, white seed colour
Igola	SGV	Large, Tan seed colour
Red beauty	Farmers	Small-medium, red seed colour
Two- seeded type	Farmers	Small, red seed colour
Serenut 11T	SGV	Released, drought tolerant, GRVD and leaf spot resistance; giant pods and seeds
Serenut 2 T	SGV	Released, highly drought tolerant, GRVD and leaf spot resistance, large seed, and Tan coloured
Serenut 6 T	SGV	Released, GRVD resistant; giant pods and seeds, Tan seed colour
Serenut 8 R	SGV	Released drought tolerant, GRVD and leaf spot resistant, Medium seed size, red seed colour

SGV, GRVD means Serere groundnut variety, and Ground rosette virus disease, respectively.

the middle rows excluding plants at the end of rows for each variety to record data on the following traits: pod yield per plant (g). Pods were sundried for two weeks and weighed to determine the dried pod yield (g/plot). Other parameters such as 100-kernel weight (g), and shelling percentage (%) were also determined. In order to measure 100-kernel weight, a random sample of 100 of well-filled seeds (avoiding shrivelled and broken ones) was drawn and its weight was recorded in grams. To quantify shelling percentage (%), pod weight was recorded from each plant in grams. Then, the weight of kernels after shelling the pods of same plant was recorded in grams, and expressed as:

Shelling percentage (%) = (Kernel weight(g))/(Pod weight (g)) × 100

Pod and seed size traits (pod diameter, pod length, Pod length – diameter ratio, seed length, seed width, ratio of seed length to seed diameter) were measured according to the method of Lal et al. (2014).

Data analysis

Data were analysed for ANOVA using Genstat version 14 (Payne et al., 2011). Means were separated using Fisher's protected $LSD_{0.05}$. Genetic parameters were computed using Excel software. Genotypic and phenotypic variances, genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), broad sense heritability, genetic advance and genetic gain were computed using standard formulas.

Estimation of variability parameters

Genetic variance

It is the variance contributed by genetic causes or the genetic occurrence of difference among the individuals due to their genetic makeup. It was calculated by using the formula given by Baye (2002),

Genotypic variance ($\delta^2 g$) = MSP- (MSe/r)

Where, $\delta^2 g$ = Genotypic variance, MSP = Mean square for phenotypes (varieties), MSe = Error mean square and r = Number of replication.

Phenotypic variance

It is the sum of variance contributed by genetic causes and environmental factors and was computed as formula given by Al-Jibouri (1958).

$$\delta^2 p = \delta^2 g + \delta^2 e$$

Where, $\delta^2 p$ = Phenotypic variance, $\delta^2 g$ = Genotypic variance and, $\delta^2 e$ = Error variance.

Genotypic coefficient of variation (GCV)

The magnitude of genetic variation existing in a character was estimated by the formula given by Burton (1952),

$$GCV = \frac{\sqrt{Vg}}{\bar{x}} X100$$

Where, Vg = Genotypic variance and $\bar{X}$ = General mean of the character under study

Phenotypic coefficient of variation (PCV)

The magnitude of phenotypic variation existing in a character was estimated by the formula given by Burton (1952),

$$PCV = \frac{\sqrt{V_p}}{\bar{x}} X100$$

Where, V_p = Phenotypic variance and $\bar{X}$ = General mean of the character under study

Heritability

Heritability in the broad sense was calculated by the formula given by Falconer and Mackay (1996),

$$H^2 = (Vg/Vp) \times 100$$

Table 2. Mean values, coefficients of variation, ranges and mean squares of some selected agronomic characters of 10 groundnut lines in selected groundnut growing regions of Uganda.

Character	Mean	CV (%)	Range	Mean square	Between	Error	P-value
			Min	Max	Lines df = 9	df = 98	
Dry pod weight/plot (g)	126.5	9.2	91.15	157.58	7437.5	136.1	<.001
Hundred seed weight (g)	48.51	9.6	34.32	69.83	2534.25	21.54	<.001
Sound mature Kernels (%	74.4	20.6	60	81.3	725.9	234.2	0.003
Shelling out turn (%)	68.06	4.3	64.91	70.37	44.17	8.72	<.001
Pod length (cm)	2.74	14	2.46	3.14	0.99	0.15	<.001
Pod diameter (cm)	1.27	14	1.12	1.35	0.077	0.032	0.016
Seed length (cm)	1.3	15	1.14	1.52	0.33	0.04	<.001
Seed diameter (cm)	0.78	13.9	0.7	0.85	0.05	0.01	<.001
PL/PD (cm)	2.13	12.1	1.86	2.38	0.66	0.07	<.001
SL/SD (cm)	1.65	14.2	1.57	1.82	0.12	0.06	0.04
Pod number	875	25.9	650	1044	296295	51245	<.001

PL/PD (cm), Df, CV, and SL/SD (cm) means Pod length to diameter ratio, Degrees of freedom, Coefficient of variation, and Seed length to diameter ratio.

Where, H^2 = Heritability (broad sense), Vg = Genotypic variance and Vp = Phenotypic variance

Expected genetic advance

It was measured by the formula proposed by Lush (1949).

$$GA = \frac{V_g}{V_p} = \sqrt{V_p} \times K = \frac{V_g}{\sqrt{V_p}} \times K$$

Where, GA = Genetic advance, Vg = Genotypic variance, Vp = Phenotypic variance, K = Selection differential (constant) i.e. 2.06 at 5% selection intensity.

Genetic gain

It was calculated by using the following formula suggested by Johnson et al. (1955),

$$\text{Genetic gain} = \frac{GA}{x} \times 100$$

Where, GA = Genetic advance and $\bar{X}$ = General mean of the character under study.

RESULTS

Variation for physical kernel traits and agronomic traits of groundnut in selected growing regions of Uganda

The results of analysis of variance are presented in Table 2. The analysis of variance revealed that mean squares due to genotypes were found to be significant for all the characters under investigation (P ≤ 0.05 to P≤ 0.01). The dry pod weight/plot (ranged from 91.15 to 157.58 g), hundred seed weight (ranged from 34.32 to 69.83 g), sound mature kernels (ranged from 60 to 81.3%), shelling out turn (ranged from 64.91 to 70.37 %), Pod length (ranged from 2.46 to 3.14 cm), pod diameter (ranged from 1.12 to 1.35 cm), pod length to diameter ratio (ranged from 1.86 to 2.38), seed length (ranged from 1.14 to 1.52 cm), seed diameter (ranged from 0.70 to 0.85 cm), seed length to diameter ratio (ranged from 1.57 to 1.82), number of pods per plot (ranged from 650 to 1044) had 126.5, 48.51g; 74.4, 68.06%; 2.74, 1.27, 1.30, 0.78 , 2.13 cm, 1.65, and 875 as average trait scores, respectively.

Association between pairs of some characters of 10 groundnut lines popularly grown in Uganda

Correlation coefficients among traits recorded in this study are presented in Table 3. Most of the traits had positive significant phenotypic association with each other**.** Dry pod weight (g/plot) was significant and positively correlated with pod diameter (r = 0.3, P ≤ 0.01), pod length (r = 0.2, P ≤ 0.05), seed diameter (r = 0.3, P ≤ 0.01), seed length (r = 0.3, P ≤ 0.01), and HSW (r = 0.7, P ≤ 0.01). Pod diameter was significantly and highly positively correlated with seed diameter (r = 0.8, P ≤ 0.01), seed length (r =0.8, P ≤ 0.01), and seed length to seed diameter ratio (r = 0.8, P ≤ 0.01).

Variances, coefficients of variation, heritability and genetic advance for traits in the groundnut lines popularly grown in Uganda

Phenotypic, genotypic and environmental variances as well as their coefficients of variation are presented in

Table 3. Pearson's correlation analysis for physical traits and selected agronomic traits of 10 groundnut lines popularly grown in Uganda.

PD_pod	-																			
PL_pod	0.8	**	-																	
Pod_No	0.0		-0.1		-															
SD_seed	0.8	**	0.5	**	0.1		-													
SL_SD	0.8	**	0.7	**	0.1		0.6	**	-											
SL_seed	0.8	**	0.5	**	0.0		0.9	**	0.8	**	-									
SMS_%	0.4	**	0.3	**	-0.1		0.5	**	0.3	**	0.4	**								
HSW	0.2	*	-0.1		-0.2	*	0.4	**	0.0		0.5	**	0.1		-					
DPW	0.3	**	0.2	*	-0.4	**	0.3	**	0.0		0.3	**	0.1		0.7	**	-			
Shelling_%	-0.1		-0.1		0.1		0.1		-0.2		0.0		0.2	*	0.3	**	0.2	**	-	
	PD_pod		PL_pod		Pod_No		SD_seed		SL_SD		SL_seed		SMS_%		HSW		DPW		shelling_%	

PD_Pod = Pod diameter; PL_pod = Pod length; SD_Seed = Seed diameter; SL_SD = ratio of seed length to seed diameter; SL_seed = Seed length; SMS = Percentage of sound mature kernels; HSW = Hundred seed weight; DPY = Dry pod yield; Shelling_% = Shelling percentage.

Table 4. Variability, heritability and expected genetic advance of some relevant agronomic characters of groundnut cultivars popularly grown in Uganda.

Traits	Phenotypic variance (δ^2_P)	Genotypic variance (δ^2_g)	Environmental variance (δ^2_E)	PCV (%)	GCV (%)	Heritability (%)	Genetic advance (%) mean
PD_pod	0.045	0.035	0.01	16.7	14.7	0.77	21.9
PL_pod	0.844	0.795	0.049	33.5	32.5	0.94	61.5
Pod_No	245050	227968.333	17081.67	56.6	54.6	0.93	101.4
SD_seed	0.036	0.032	0.004	24.3	22.9	0.89	40.2
SL_SD	0.061	0.043	0.018	15	12.5	0.7	17
SL_seed	0.296	0.283	0.013	41.7	40.8	0.96	78.8
SMS_%	491.7	413.633	78.067	29.8	27.3	0.84	44.9
HSW	2512.71	2505.53	7.18	103.3	103.2	1	211.2
DPW	7301.4	7256.033	45.367	67.5	67.3	0.99	137.2
shelling_%	35.45	32.543	2.907	8.7	8.4	0.92	15.3

PCV = Phenotypic coefficient of variation; GCV = Genotypic coefficient of variation; H^2- bs = Broad sense heritability; GAM = Genetic gain as percentage of the mean; PD_Pod = Pod diameter; PL_pod = Pod length; SD_Seed = Seed diameter; SL_SD = ratio of seed length to seed diameter; SL_seed = Seed length; SMS = Percentage of sound mature kernels; HSW = Hundred seed weight; DPY = Dry pod yield; Shelling_% = Shelling percentage.

Table 4. Similarly, heritability and expected genetic advance are presented in the table. Both the variances of phenotype and genotype of all traits studied were low except, those of number of pods per plot, HSW, and Dry pod weight/plot had low. Correspondingly, both coefficients of variation

for the phenotype and genotype were generally low, except for number of pods per plot, seed length, hundred seed weight, and dry pod weight. Heritability ranged from 70 to 100% whereas expected genetic advance ranged from low 15.3% in shelling percentage to 137% in hundred seed weight.

DISCUSSION

Coefficients of variation and ranges of the 10 seed and agronomic characters of groundnut explained that significant variation existed in all the characters. Similar results were also reported by Patidar et al. (2014), Maurya et al. (2014), Shukla and Rai (2014), Rai et al. (2014), Rao et al. (2014) and Nalluri et al. (2017). Ranges were very high for all the characters. The wide range in values of the traits was adequate to distinguish the groundnut lines using these traits. The low CVs in the values of the traits may be expected because the lines comprise landraces and popular released groundnut varieties which over several generations have resulted in fixation of genes at different loci.

The phenotypic variances were higher than the genotypic variances for all traits implying that environment influences the inheritance of these characters, and effect varied with trait under consideration. This agrees with findings of Maurya et al. (2014) and Zekeria et al. (2017). Low coefficients of variation for the phenotype and genotype were observed, except for number of pods per plot, seed length, hundred seed weight, and dry pod weight, encourages the use of yield parameters in the selection of suitable parents for crosses or line improvement. This agrees with finding of Shukla and Rai (2014), and Nalluri et al. (2017). Pod and seed traits such as pod length, percentage of mature kernels, and seed diameter may also be considered in case there is need to support the yield parameters because their coefficients of variation were comparatively large. Similar findings were reported by Patidar et al. (2014), and Maurya et al. (2014).

Dry pod weight (g/plot) was positively correlated with pod diameter, pod length, seed diameter, seed length, and HSW. Roy et al. (2003), Gopal (2008), and Kakeeto (2017) reported a similar result. Pod diameter was significantly and highly positively correlated with seed diameter, seed length, and seed length to seed diameter ratio. This observation implies that instead of tediously measuring seed sizes, an easier measurement can be done using pod diameter.

Heritability is the percentage of phenotypic variance that is attributed to genetic variance. In the present study, heritability was high (>80%) for most traits studied. High heritability indicates that the environmental influence is minimal on the characters. This implies that, any of the characters studied here can therefore be used for selection. Nalluri et al. (2017), John et al. (2008), and Narasimhulu et al. (2012) have also reported high heritability for different yield contributing traits in groundnuts. High value of heritability in broad sense indicates that the character is least influenced by environmental effects. Similar observations were made by Shukla and Rai (2014).

Heritability estimates along with genetic advance as per cent of mean are more helpful in predicting the gain under selection than heritability estimates alone. The expected advance that was low for pod diameter, seed diameter, seed length to width ratio, and shelling percentage may be compensated for by their high heritability. High heritability coupled with high genetic advance as percent of mean was recorded in pod length, pod number per plot, seed length, and hundred seed weight indicating the preponderance of additive gene action in controlling the inheritance of this character and offers high feasibility for improvement through simple selection procedures. Similar results were reported by John et al. (2008), Thakur et al. (2011), and Bhargavi et al. (2017).

Moderate heritability accompanied with low genetic advance as per cent of mean was observed in pod diameter, seed diameter, seed length-width ratio, shelling per cent indicating the preponderance of non-additive gene action as well as influence of environment. The improvement of this trait might be possible through heterosis breeding. Similar result was reported by Korat et al. (2009) and Zaman et al. (2011) and Bhargavi et al. (2017).

Conclusion

High heritability coupled with high genetic advance as per cent of mean was recorded in pod length, pod number per plot, seed length, and hundred seed weight indicating the preponderance of additive gene action in governing the inheritance of these characters and offers scope for improvement through simple selection procedures. Moreover, this study also found pod diameter to be highly positive and significantly correlated with seed length, seed diameter, seed length to width ratio, and pod length; it implies instead of using pod yield, pod number and pod diameter could be considered for evaluating large populations of groundnut lines for further improvement. The results from the present study were outcomes of a one-season evaluation. It is generally believed that evaluation carried out across the year (at least two seasons) would derive reliable conclusions on the range of characters in this study. Therefore, our results provide some useful information for genetic improvement of the cultivated groundnut.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Evaluation of the effectiveness of different trap designs for the monitoring of *Drosophila suzukii* (Matsumura, 1931) (Diptera: Drosophilidae) in blackberry crop

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Spotted Wing Drosophila (SWD), *Drosophila suzukii* is one of the most important pests in berry crops around the world. In this study, different models of traps were evaluated for monitoring adult SWD. The study was conducted in a commercial blackberry orchard of the cultivar Chester, in the municipality of Vacaria, RS, Brazil in May 2016. The treatments consisted of three trap designs, namely the European model (Hemitrap®), American model (plastic pot with 750 ml of capacity), and Brazilian model (red dyed, and colorless polyethylene terephthalate (PET) bottle of 250 ml of capacity). A total of 1,572 adults of SWD were captured, as 867 males and 705 females. The mean sexual ratio was of 0.56 ± 0.03 with no difference among trap models. The trap Hemitrap® showed the highest capture values for SWD adults as well as for other Drosophilidae. The American model did not show good results being surpassed by the PET bottle trap. When considering the number of entrapped insects per milliliter of attractant, per area of entrance, per evaporative surface, and per selectivity, the colorless PET trap (Brazilian model) is the most effective.

Key words: Spotted wing drosophila, berry crops, South America, traps.

INTRODUCTION

Blackberry crop is cultivated mostly by small-hold farmers due to the low investment cost and its high profitability (Pagot and Hoffmann, 2003; Poltronieri, 2003). Although blackberry has favorable characteristics for production in family agriculture, pest attack has been limiting the expansion and profitability of the crop, due to the struggle of controlling the pests as well as the rejection of whole fruit lots by the industry when detecting the presence of

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alive insects in the fruits.

The recent registry in Brazil of *Drosophila suzukii* (Matsumura, 1931) (Diptera, Drosophilidae), a pest known worldwide as Spotted Wing Drosophila (SWD) has caused concern among producers and technicians due to the significant damage it causes to the crops, which may reach 100%. SWD is currently expanding worldwide, attacking several host crops: blackberry, strawberry, blueberry and raspberry (Lee et al., 2011; Walsh et al., 2011). In Brazil, the pest was reported in the South of the country in strawberry crops, causing damage of around 30% of the production (Santos, 2014). Due to the high potential of dissemination, rapid population growth and high number of host plants, full attention should be given to SWD in host crops (Teixeira and Rego, 2011).

The establishment of SWD monitoring strategies is an initial step for pest detection in the crops and to back decision making of strategies to control the dissemination. Santos (2014) suggested the use of attractant traps, made with polyethylene terephthalate (PET) bottles (250 ml) to monitor SWD, although, no data regarding the efficiency of this model of trap in the field was presented. In the USA it is common to use traps made with transparent plastic pots for monitoring *D. suzukii* (Lee et al., 2012). In Europe, the use of a commercially available trap (Hemitrap®) has been recommended for monitoring as well as mass control of SWD due to its high efficiency (Probodelt, 2015). It is agreed that the different types of traps, that is, different colors, shapes and number of holes, will affect the rate of insects captured. For example, the external color of the trap has been pointed out as an important factor for SWD, with superior results using yellow, red or black color (Basoalto et al., 2013; Lee et al., 2013). The trap shape is also a characteristic to be analyzed, since the volume of attractant inside the trap influences the amount of volatiles released to the field, and consequently the capture rate of the pests (Lee et al., 2013).

Because it is a recently introduced pest in Brazil, there are still few studies that provide robust knowledge for the monitoring and management of *D. suzukii* in host crops. Thus, the present study aimed to evaluate SWD capture with different trap designs in a commercial blackberry orchard.

MATERIALS AND METHODS

The experiment was conducted in a commercial orchard of blackberry cv. Chester, located in the municipality of Vacaria, State of Rio Grande do Sul, in Southern Brazil (28° 28'40.18 "S and 50° 58'7.40" W) during the month of May, 2016. The experimental design was of randomized complete blocks with four treatments (trap designs) and five replications. The traps were filled with attractant based on biological yeast, sugar and water (Santos, 2016) in the recommended amount for each trap model.

The first treatment consisted of traps made with transparent plastic pots of 14 cm of height by 11 cm in diameter, named as the "American model" (Lee et al., 2013) (Figure 1A). The trap had 11 holes of 4 mm of diameter for the arrival of the insects (138.16 mm^2 of entrance area), located at the upper edge of the trap, near the lid, and filled with 250 ml of attractant. The second treatment consisted of the commercially available yellow color Hemitrap® with 15 cm in height and 12.5 cm of diameter, named as "European model". The trap had 21 holes of 7 mm diameter (807.8 mm^2 of entrance area), arranged in three groups of seven holes each, symmetrically distributed around the trap in its upper third, and filled with 250 ml of the attractant (Figure 1B). The third and fourth treatments consisted of traps made with PET bottles of 250 ml Coca Cola® soda pop, referred to as "Brazilian model". The traps contained five holes with 4 mm of diameter (62.8 mm^2 of entrance area), equidistant 2 cm, in the lower third of the trap which contained 5 cm in diameter. In this trap, a volume of 40 ml of the attractant was used. The difference between treatments three and four was the color of the trap: transparent and red, respectively (Figure 1C and D).

The traps were placed in the field, and arranged in randomized complete blocks (plant rows), equidistant from each other in 6 m, at a height of 1.30 m from the ground level. They were inspected every two days, and the captured insects removed, packed in plastic pots, and taken to the Embrapa Grape and Wine laboratory in Vacaria, RS, for screening. SWD adults were segregated into both sexes and computed under stereomicroscope, along with the number of other Drosophilae adults present in the samples. The analyzed variables were: total number of adults of *D. suzukii* and sexual ratio; total number of other Drosophilidae captured; mean SWD per attractant volume (ml) and mean SWD as a function of the total insect entrance area in each trap model. The total number of holes, total entrance area and evaporation surface of the attractant were considered for each trap.

The data were tabulated and analyzed for normality by the Shapiro-Wilk test and homoscedasticity by Hartley and Bartlett. Treatment averages were compared by the Tukey test at 5% probability using Statistica 6.0 software.

RESULTS AND DISCUSSION

A total of 1.572 adults of *D. suzukii* were collected in the experiment, being 867 males and 705 females. The sexual ratio was approximately 1:1 in all trap models, indicating that the traps did not interfere with the sex-trapping behavior in the evaluated orchard (Table 1). Klesener et al. (2018), in southern Brazil, also found that there are no significant differences in the sexual ratio of SWD in berry crops.

Considering the total entrapment values, the European model (Hemitrap®) was the one that captured the largest number of SWD, followed by the transparent and red color PET bottles traps, whereas the American model was the one with the lowest value (Table 1). In relation to the color, different studies have shown that red color is more attractive to SWD than transparent (Lee et al., 2012; Basoalto et al., 2013; Lee et al., 2013). However, in the study conducted by Mazzetto et al. (2015), it was pointed out that a lower entrapment rate of red color traps in blueberry crops, similarly to the results found in this experiment, where the red color trap did not promote

Figure 1. Trap designs used in the study. (A) Transparent plastic pots (American model); (B) Hemitrap® (European model); (C) Transparent PET bottle; (D) Red color PET bottle (Brazilian model).

Table 1. Total number and sex ratio of adults of *Drosophila suzukii* collected in different trap designs in a commercial orchard of blackberry cv. Chester. Vacaria, RS, May 2016.

Model	Number of trapped insects			
	Male	Female	Total	Sex ratio
Brasilian model Transparent	202	156	358	0.58±0.18
Brasilian model Red	174	122	296	0.58±0.01
European model	394	306	700	0.57±0.04
American model	97	121	218	0.55±0.12
Total	867	705	1.572	0.56±0.03

greater SWD capture in the blackberry orchard.

In relation to the greater entrapment of the European model, some factors are important; for example, the greater volumetric capacity and surface area to release the volatiles of the attractant to the field. Lee et al. (2013), discussed this, and affirmed that there is an increase in the capture of pests as a function of the amount of attractant in the trap, but the increase is not linear, because at a 225% increase in the surface area of the attractant's volatiles release, there was an increase of only 12% in capture rate. For Lee et al. (2012) and Renkema et al. (2014) the greatest capture is related to the entrance area of the insects in the trap (area occupied by holes). This result corroborates the findings of this trial, since it is precisely the European model trap (Hemitrap®) that presented the largest insect entry area

Table 2. Mean (± SE) of adults of *Drosophila suzukii* captured in different trap designs, as a function of the amount of attractant (ml), number of holes, insect entrance area (mm^2) and evaporation surface.

Model	Insect/ml	Insect/hole	Insect/entrance area (mm^2)	Insect/evaporation surface (cm^2)
Brasilian model Transparent	1.79±0.61[a]	14.3±4.89[a]	1.14±0.39[a]	3.65±1.24[a]
Brasilian model Red	1.48±0.17[ab]	11.8±1.36[a]	0.94±0.11[ab]	3.02±0.34[ab]
European model	0.56±0.06[bc]	6.6±0.73[ab]	0,17±0.01[c]	1.14±0.12[bc]
American model	0.17±0.04[c]	3.9±0.96[b]	0.31±0.07[bc]	0.45±0.11[c]
Coefficient of variation (%)	14.01	22.2	11.37	18.22

Means followed by the same letter in the column do not differ statistically by the Tukey test at 5% of probability.

Table 3. Number and percentage of *Drosophila suzukii* and other Drosophilidae collected with different trap designs in commercial blackberry orchard cv. Chester. Vacaria, RS, May 2016.

Model	Trapped insects				
	Drosophila suzukii		Other Drosophilidae		Total
	Number	%	Number	%	
Brasilian model Transparent	358	80	89	20	447
Brasilian model Red	296	90	33	10	329
European model	700	68.2	326	31.8	1.026
American model	218	84.2	41	15.8	259
Total	1.572	76.6	489	23.7	2.061

(807.8 mm^2).

Thus, when evaluating the number of SWD captured in relation to the attractant volume, number of holes, insect entrance area and evaporation surface of the attractant, the Brazilian model (transparent) was superior with significantly higher entrapped insects/ml; insects/ entrance area and insects/evaporation surface (Table 2). In this new analysis, the European and American models were similar, without significant differences between them (Table 2).

In this analysis, the "Brazilian model" (transparent) was efficient for the population evaluation of SWD, since with a low amount of attractant (40 ml), it was already possible to measure the population of the pest in the field. The best performance was also observed when analyzing the evaporation surface area of the attractant, since the Brasilian model trap has the smallest area (62.8 mm^2) than the others (Table 2).

Another important aspect of the traps is the location of the holes, which in the Brazilian model are in the lower third and near the surface of the attractant. In addition, the convex shape of the bottle in the region (Coca-Cola®), makes it difficult for the insects to escape from the trap in function of the SWD positive phototropism. This does not occur in the American model because the holes are in the top position of the trap, near the lid of the pot, just where there is more accumulation of insects, which allows them to escape. Comparing the European model, Hemitrap®, with the American model, which contained the same attractant volume (250 ml), the largest capture was determined by the position and number of holes, which in the Hemitrap® model seemed to be more adequate.

Regarding other Drosophilidae, a total of 489 adults were collected in the experiment, representing 23.7% of the total drosophila sampled in this study. This result reflects a certain selectivity of the attractant used and proposed by Santos (2016), since larger percentages of other Drosophilidae are mentioned in studies with SWD, as for example in the use of apple vinegar (Lee et al., 2012). From the traps evaluated, the Brazilian model showed selectivity for SWD collection of 90 and 80%, in red and transparent color, respectively. Close result was obtained with the American model (84.2%), while in the European model the lowest value (68.2%) was recorded (Table 3).

The results obtained in this study showed the possibility of using traps made with PET bottles to monitor SWD in blackberry orchards. This type of trap does not have the highest number of collected insects, an attribute of the European model trap, but when considering other aspects such as proportion of insects per ml of attractant, number of holes and entrance area, the PET trap (Brazilian model) presented statistically superior performance. Another important aspect is to be a reusable material, with low cost for trap confection. In addition, the Brazilian model presented low capture of other Drosophilidae, which simplifies the sorting of collected material. The reduced amount of attractant used in the PET model (Brazilian model) is another favorable point, because it uses only 40 ml, against 250 ml of other traps. It should be noted that the Brazilian model proposal is for use in SWD monitoring to support decision-making control strategies, not for mass collection strategies, where the European model, Hemitrap® trap, would be the most appropriate.

For Lee et al. (2012, 2013), the most efficient trap model for SWD monitoring should be the one with the highest insect capture, suitability to the needs of the producer, ease of handling and acquisition. Thus, traps made with PET bottles proved to be an efficient alternative to use for SWD monitoring in blackberry orchards.

Conclusions

The evaluated traps do not interfere in the capture behavior according to sex in blackberry orchard. The European model, Hemitrap® trap, captures the largest number of SWD adults and other Drosophilidae.

By taking into consideration the number of insects collected per ml of attractant, per entrance area, per hole, per evaporation surface and selectivity, the Brasilian model transparent trap is the most efficient.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Analysis of factors affecting the demand for inorganic fertilizer in Boricha and Wondogenet Districts, Southern Ethiopia

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A study was undertaken to analyze factors affecting the demand for inorganic fertilizer in Boricha and Wondogenet farming Districts, Southern Ethiopia. Data on gender, educational level, farming experience, health status, soil fertility status, organic fertilizer used, access to inorganic fertilizer, ownership and size of cultivated farm, on-farm income, contact with DAs, availability of certified seed, and credit access were recorded using structured and semi-structured questionnaire on purposively selected one hundred eighty farmers. Descriptive statistics and econometric methods were employed to analyze the data using Statistical Package for Social Science (SPSS), version 19.0. The regression model revealed the number of oxen owned, cultivated farm size, access to certified seed, availability of fertilizer, contact with DAs, and on-farm income had a significant influence on the demand of inorganic fertilizer in the districts. The study suggested intensifying cultivated farms, sustaining extension services, strengthening fertilizer credit facility, providing improved seeds, and increasing on farm income of the farmers require immediate intervention in the study districts.

Key words: Factors, affecting, demand, inorganic fertilizer, South Ethiopia.

INTRODUCTION

Major economic and social measures have shown that agriculture is the dominant sector in the Ethiopian economy which contributes 55% of GDP, 80% of employment opportunity, 60% of export earnings and 70% of raw materials for domestic industries (World Bank, 2016). Despite its highest share in the country’s economy, the performance of the sector cannot bridge the wide food demand of the increasing population (Eilittä, 2017; Anonymous, 2018). Projections showed the population will continue to grow at a faster pace and the urgency of maximizing crop production through adoption of improved agricultural technologies like fertilizer is of paramount importance (CSA, 2015; Freeman et al., 2016). In line with this, the government of Ethiopian has given top attention for fertilizer policy and strenuous efforts have been underway to adopt, promote and use it

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(FDRE, 2015). Although, the total consumption of chemical fertilizers has shown an increasing trend in the country in general, the demand for inorganic fertilizer in Borciha and Wondogenet districts, Southern Ethiopia are still below the expected due to various bottlenecks (Roberts, 2013; MoARD, 2015). This study was initiated to provide recent empirical evidences about the factors affecting the demand for inorganic fertilizer in the two districts so as to suggest policy implications for future intervention strategies of the region.

METHODOLOGY

Study area

This study was conducted in two major crop growing districts, Boricha and Wondogenet, Southern Ethiopia; both situated at about 270 km away from the capital Addis Ababa. Geographically, Boricha district has total area coverage of about 588.1 km^2 (CSA, 2015). It is located at 6°56' 30.8" North Latitude as well as 38° 25' 07.4" East Longitude. The district is characterized by lowland (Kola) and mid altitude (Woina dega) with a mean annual rain fall (mm) and temperature (°C): 801- 1000 and 17.6-22.5, respectively. The major crops growing include maize, banana, pepper, sweet potato, yam, enset, coffee, and haricot bean. Similarly, Wondogenet district has total area coverage of about 232 km^2 (CSA, 2015). It is located at 70°4' 55.7" N latitude and 38°36' 56.1" E longitude. The district is characterized by mid altitude (Woina dega) and Dega with a mean annual rain fall (mm) and temperature (°C): 1001-1400 and 15.1-22.5, respectively. The area is known in growing crops like maize, barley, kchat, sugarcane, potato, onion, enset, peas, and beans.

Sample size and sampling technique

One hundred and eighty respondent farmers, 90 from two kebeles, Konsore fulassa and Gesera kuwe in Boricha district and the rest 90 from Ado and Wosha Soyama kebeles of Wondogenet district were considered. The respondents were 45 farmers per kebele comprised both adopters and non-adopters of inorganic fertilizers. Data was collected using multi-stage purposive sampling technique through distribution of structured and semi structured questionnaire, interview and observation. In doing so, the respondents were classified based on their level of income, gender, education level, farming experience, health status, leadership position, farm ownership, number of family, oxen own, on-farm and non-farm income generate.

Data collected

Before conducting the actual survey of the study, pre-testing was carried out accounting for 50 randomly selected farmers (25 farmers/district) and some amendments were made on the final questionnaire. Data was collected from primary and secondary sources through distribution of questionnaire, interview of farmers at their slack time, and frequent observation of the districts.

Primary data

Structured questionnaire was distributed to those farmers who can read and write; otherwise interview was made through the direct translation of the questionnaire into their local language. Qualitative data about the patterns and types of activities of the people and their behavior was gathered informally through direct observation of the study areas and informal discussions with key Agriculture development agents, agriculture sector officers, administrators, and ethnic leaders.

Secondary data

Data about agricultural inputs supplied and consumed, physical characteristics, population size and crop yield were gathered through thorough reviewing and examination of reports as well as records of published and unpublished documents of the districts.

Data management and analysis

Questionnaires were coded, entered into Microsoft excel sheet and analyzed using Microsoft Excel programs. Descriptive analysis of the household characteristics were narrated and summarized into tables using sample mean and percentages to describe the factors that affect the rate of inorganic fertilizer. Econometric analysis method was also employed using Statistical Package for Social Sciences (SPSS) Version 19.0 and Multiple linear regression model was constructed to show which factor affects the demand for inorganic fertilizer by how much. Designation of the model was $Y = B_o + B_1X_1 + B_2X_2 + B_3X_3 . . . B_nX_n + E$, where the independent variables X_1, X_2, $X_3 . . . X_n$ denote factors affecting the rate of inorganic fertilizers use like the income of the farmer, price of fertilizer, size of the land, type of the soil, type of the crop, knowledge, farming experience, on time availability, and application of other organic fertilizers. The parameter B_o represents the constant coefficient value, B_1, B_2, $B_3 . . . B_n$ denote the coefficient numbers that express the effect of factors (X_1, X_2 and $X_3 . . . X_n$) on Y, Y denotes adoption level of inorganic fertilizer by the farmers, and E represents the error term.

Definition of variables in the model and hypothesis

In the study, the rate of inorganic fertilizer used was treated as dependent variable of the model (FERTILIZER) whereas those variables that are supposed to influence rate of inorganic fertilizer use were considered as independent variables and are explained as follows:

(i) Sex of the household head (SEX): This is a dummy variable which takes a value 1 if the household head was male and 0 for female. Therefore, it was assumed that male-headed households have more access to fertilizer use.
(ii) Age of the household head (AGE): Older farmers may accumulate more wealth than younger ones so as to finance fertilizer purchase. Hence, farmers who are older were assumed to adopt higher rate of fertilizer than the younger ones. Moreover, this variable was hypothesized as it positively influences fertilizer adoption and the intensity of use.
(iii) Farming experience (FAEXP): This represents the number of years that the farmers have passed on their farming work. Thus, a farmer with a long history of farming can adopt higher rate of fertilizer than the one who has short farming experience. Therefore, farming experience was hypothesized as it positively influences adoption level of fertilizer.
(iv) Educational level of the household head (EDUCN): This is a dummy variable, which takes a value 0, 1, 2, 3, 4 if the household head was illiterate, can read and write (basic education), primary school, secondary school and higher institution education, respectively. Farmers with ability to read and write and other education were expected to have an advantage in obtaining information and understand the benefit of fertilizer use. So,

educated farmers were assumed to adopt higher rate of fertilizer than illiterate ones. Therefore, education was hypothesized as it positively influences adoption level of fertilizer.

(v) Availability of family labor force (FAMLBR): New technologies such as fertilizer could increase the seasonal demand of labor so that adoption is more attractive to households with a large number of active labor forces. Hence, a farmer having large number of family labor force can adopt higher rate of fertilizer than a farmer with small number of family labor force. So, it was expected that this variable would have a positive impact on adoption and intensity of fertilizer use.

(vi) Health status of the household head (HEALTH): This is a dummy variable, which takes a value 0 if the household head was seriously ill (unable to perform main farm activities) and 1 if the household head was healthy during the main season. This variable can influence adoption and intensity of fertilizer use not only in physical availability of labor but also the management aspect of the farm household. Thus, households who have a healthy head are in a better situation to adopt new technology than those with sick ones. So, this variable was expected to positively influence adoption and intensity of fertilizer use.

(vii) Manure application (MANUAPP): This is a dummy variable, which takes a value 1 if the household uses manure and 0 if not. Farmers who have the culture of manure application can and/or not adopt small rate of inorganic fertilizer. Hence, this variable was expected to have negative impact on inorganic adoption.

(viii) Cultivated farm size (CFARMS): This refers to the total cultivated land that belongs under a particular farmer holding. A farmer with large farm size is assumed to be relatively wealthy, and then s/he can buy higher rate of inorganic fertilizer than a farmer with smaller farm size. Thus, this variable was hypothesized as it would have positive impact on farmers' demand for inorganic fertilizer adoption.

(ix) On-farm income (ONFI): This refers to the total amount of money farmers could earn from on-farm activities annually. It was the sum of current market value of output obtained from crop production, income from the sale of livestock and their products as well as by-products, and income from the sale of trees and their products. So, a farmer who earns higher on-farm income could purchase higher amount of inorganic fertilizer than the one who earn smaller amount. Thus, it was hypothesized as it would have a positive influence on farmers' adoption level of inorganic fertilizer.

(x) Non-farm income (NOFI): Some farmers in the study area may be engaged in non-farm activities such as handicraft, petty trade, office guarding and off-farm activities like working as daily laborer on government and private farms as well as the farm of others, which help them to earn additional income. The influence of this variable on the farmers demand for fertilizer can be positive or negative. Since this additional income sources increase the farmers' financial capacity, it increases the capacity of the farmers to invest in new technologies. In this aspect, availability of income from non-farm activities was hypothesized to be one of the factors that influence farmers' adoption for fertilizer positively. On the other hand, when farmers are engaged in non-farm activities, it shares the working force of the household that would be engaged in farming. Hence, this variable was hypothesized as it negatively influences the inorganic fertilizer adoption level of the farmers.

(xi) Number of oxen owned (OXEN): Defined in terms of number of oxen that the household head has for farm operations. A farmer with many oxen could rent the extra oxen to other farmers and fetch better wealth to purchase fertilizer and could also operate his/her farm properly as well as on time. Hence, a farmer having larger number of oxen could adopt higher rate of inorganic fertilizer than a farmer who have and/or do not have small number of oxen. Thus, this variable was expected to have positive influence on adoption and intensity of fertilizer use.

(xii) On time availability of fertilizer (ONTIME): This is a dummy variable, which takes a value 1 and 0 if the household head says yes and/or no on-time available of fertilizer, respectively. So, a farmer who can get on-time availability of inorganic fertilizer can adopt better than the one who cannot get on-time.

(xiii) Frequency of contact with DAs (FRCNT): A continuous variable which refers to the number of contacts that the households meet with DAs to get advice. A farmer who has frequent contact with DAs could adopt higher rate of inorganic fertilizer than a farmer who has less contact with DAs. Thus, this variable was hypothesized as it influences farm households' adoption level of fertilizer positively.

(xiv) Transportation access (TRANSPORT): This is a dummy variable, which takes a value 1 if the household has transportation access and 0 if not. Those households having transportation access are expected to adopt inorganic fertilizer in better than those farmers who have shortage of transport access. Therefore, this variable was hypothesized as it influences farm households' adoption level of fertilizer positively.

(xv) Soil fertility status (FERTILITY): This is a dummy variable, which takes a value 0, 1, and 2 if the soil fertility level is poor, medium and highly fertile, respectively. The more the fertile the soil is, the lower amount of inorganic fertilizer that would be required by the farmer. So, a farmer whose land is less fertile can adopt higher rate of inorganic fertilizer than those farmers whose lands are medium or highly fertile.

(xvi) Availability of certified seed (SEED): This refers to the total amount of seed that the households have given from the agricultural office. Therefore, this variable was hypothesized as it influences farm households' adoption level of fertilizer, positively.

(xvii) Leadership position (LEADRSP): This is a dummy variable, which takes a value 0 if the individual has not leadership poison and 1 if the individual has leadership poison. Therefore, this variable was hypothesized as it influences farm households' adoption level of fertilizer, positively.

(xviii) Credit access (CREDIT): This is a dummy variable, which takes a value 0 if the individual has no credit access and 1 if the individual has credit access. Therefore, this variable was hypothesized as it influences farm households' adoption level of fertilizer, positively.

RESULTS

Descriptive analysis of household characteristics

Sex of household head

Of the total respondents, 67.5 and 85.0% of the households were adopters while 32.5 and 15.0% were non adopters of inorganic fertilizers in Boricha and Wondogenet districts, respectively. Out of the adopters, female-headed accounted for 22.5% in Boricha and 37.5% in Wondogenet districts, while the rest 77.5 and 62.5% were male-headed in Boricha and Wondogenet districts, respectively (Table 1). In Boricha district, 55.6% of female-headed and 71.0% of male-headed households adopted inorganic fertilizer during the survey year. The corresponding figures in Wondogenet district were 73.3% for female-headed and 92.0% for male-headed households. The proportion of male-headed households who adopt inorganic fertilizer was greater than that of female-headed households in both districts which corroborates the finding of Akpan et al. (2013). This might be attributed to insecure the economic position of the female-headed households, shortage of labor, limited

Table 1. Sex category of respondent farmers in Boricha and Wondogenet Districts.

District	Farmers group	Sex				Total	
		Female		Male			
		N	%	N	%	N	%
Boricha	Adopter	22	55.6	119	71.0	141	67.5
	Non-adopter	18	44.4	21	29.0	39	32.5
	Total	40	100.0	140	100	180	100.0
	% of total	22.5		77.5		100	
Wondogenet	Adopter	42	73.3	23	92.0	34	85
	Non-adopter	15	26.7	2	8.0	6	15.0
	Total	67	100	113	100	180	100.0
	% of total	37.5		62.5		100.0	

% of total refers to the percentage calculated out of the total sample size of each district, N-number of respondent.

Table 2. The average family size by age category in Boricha and Wondogenet districts.

Age category	District					
	Boricha			Wondogenet		
	Male	Female	Total	Male	Female	Total
0-14 years	1	-	1	1	1	2
15-64 years	1	1	2	1	1	2
>64 years	1	-	1	-	1	1
Total	3	1	4	2	3	5

access to factors of production and social position of the household head as well as lack of awareness about new technologies. Again the proportion of both male-headed and female-headed sample respondents of Wondogenet district who adopt inorganic fertilizer was greater than that of Boricha district. This depicts that farmers in Wondogenet were better in adoption of inorganic fertilizer than those in Boricha district.

Family size by age category of the household head

The average family size of Boricha and Wondogenet district households were 4 and 5, respectively (Table 2). The average number of economically active labor age group (15 to 64 years) in both districts was similar (2) which directly agrees with Serge et al. (2017) and Mahmuda et al. (2018) estimation. On average, 50% family size of Boricha farmers observed actively engaged in an economic activity better than Wondogenet district farmers (40%).

Econometric analysis

The explanatory variables, viz: number of oxen owned, cultivated farm size, access to certified seed, price of fertilizer, on-time availability of fertilizer, access to fertilizer credit, frequency of contact with DAs, on-farm and off-farm income, as well as soil fertility status of the farmland in Boricha and number of family labor force, number of oxen owned, cultivated farm size, farming experience, access to certified seed, manure application, on time availability of fertilizer, access to fertilizer credit, frequency of contact with DAs, and on-farm income in Wondogent had direct influence on the rate of inorganic fertilizer use (Table 3).

Multi-collinearity test results

As shown in Table 4, variance inflation factor (VIF) values for all continuous variables in Boricha district were small (<10). This shows there is no serious multi-collinearity problem among the continuous variables when tested independently. Thus, all the continuous variables were included in the model. However, the VIF values of access to certified seed (30.095) and frequency of contact with DAs (18.056) in Wondogenet district showed serious multi-collinarity problem. This would bias the T-statistics and coefficient estimates unless remedial measures taken. To escape from such problem, dropping of all but one of the collinear variables from the analysis is one of the suggested methods (Bul Agric, 2016; Dillon and Barrett, 2017). Thus, access to certified seed with the highest VIF value (30.095) was omitted and the

Table 3. Pearson correlation values for the explanatory variables.

Explanatory variable	Pearson correlation value	
	Boricha	Wondogenet
Sex	0.248	0.118
Age	0.155	0.136
Educational level	-0.155	0.009
Health status	0.179	-0.009
Number of family labor force	-0.178	0.424**
Leadership position	0.054	0.245
Number of oxen owned	0.379*	0.459**
Cultivated farm size	0.822**	0.858**
Farming experience	0.225	0.448**
Access to certified seed variety	0.800**	0.964**
Manure application	-0.101	0.443**
Fertilizer input price	0.451**	0.217
On time availability of fertilizer	0.619**	0.415**
Transportation access	0.067	0.190
Access to fertilizer credit	0.565**	0.376*
Frequency of contact with Das	0.898**	0.973**
On-farm income	0.729**	0.880**
Off-Farm	0.324*	-0.013
Soil fertility status	0.696**	-0.204

** and *Correlation significant level at 1 and 5%, respectively.

Table 4. VIF of the continuous variables for Boricha and Wondogenet districts.

	Continuous variable	Boricha		Wondogenet	
		Tolerance ($1-R_i^2$)	VIF	Tolerance ($1-R_i^2$)	VIF
1	Number of Family labour force	0.833	1.201	0.405	2.468
	Number of oxen owned	0.584	1.713	0.367	2.722
	Cultivated Farm Size	0.192	5.214	0.106	9.428
	Farming experience	0.854	1.171	0.520	1.924
	Access to certified seed	0.367	2.723	0.033	30.095
	Frequency of contact with DAs	0.235	4.257	0.055	18.056
	Total on-farm Income	0.211	4.750	0.206	4.866
	Total off-farm Income	0.723	1.382	0.742	1.348

multicollinarity problem of Wondogenet district was corrected and all continuous variables had a VIF value of less than 10.

Similarly, the contingency coefficients were computed in order to check the degree of association among the remaining ten discrete variables and there was no serious problem of association among the variables in both districts when tested independently. This indicates no variable had a contingency coefficient value that approaches to 1 (perfect correlation). Thus, all the discrete variables were included in the model for further collinearity diagnosis and analysis.

In the study, number of oxen owned (OXEN), cultivated farm size (CFARMS), on time availability of fertilizer (ONTIME), frequency of contact with DAs (FRCNT), total on-farm income (ONFI) and access to certified seed (SEED) had significant ($P \leq 0.1$) effect on the adoption of inorganic fertilizer in Boricha district (Table 5). Likewise, with the exception of access to certified seed that has been dropped away from regression analysis for the correction of multi-collinearity problem, number of oxen owned (OXEN), cultivated farm size (CFARMS), on time availability of fertilizer supply (ONTIME), frequency of contact with DAs (FRCNT), and total on-farm income (ONFI) in Wondogenet district had significantly affect explanatory variables (Table 5).

Table 5. Regression result for significant explanatory variables.

Significant variable	Coefficients		t-value		VIF	
	Boricha	Wondogenet	Boricha	Wondogenet	Boricha	Wondogenet
(Constant)	-35.32	-32.98	-2.12	-2.37	-	-
Number of oxen owned	-5.99**	-9.73**	-2.51	-2.60	1.88	2.64
Cultivated farm size	15.87***	23.66**	3.08	2.44	5.41	5.83
On time availability of fertilizer	22.46***	20.17**	2.73	2.31	2.74	1.67
Frequency of contact with DAs	24.17***	41.73***	5.01	12.98	4.99	5.79
Total on-farm income	0.00***	0.00*	3.29	2.00	5.75	5.21
Access to certified seed	4.029***	****	4.647	****	6.736	*****

****Omitted from regression analysis for Wondogenet district due to multicollinarity problem. ***Significant at 1% probability level. **Significant at 5% probability level. *Significant at 10% probability level.

Table 6. Multiple linear regression coefficients after multicollinarity problem correction for Boricha.

Model		Unstandardized Coefficients		T	Sig.	95% Confidence Interval for B		Collinearity Statistics	
		B	Std. Error			Lower Bound	Upper Bound	Tolerance	VIF
	(Constant)	-35.32	16.674	-2.12	0.04	-69.42	-1.22	-	-
	Number of oxen owned	-5.99	2.39	-2.51	0.02	-10.88	-1.11	0.53	1.88
	Cultivated farm size	15.87	5.15	3.08	0.004	5.34	26.41	0.18	5.41
	Access to certified seed	4.03	.87	4.65	0.00	2.26	5.80	0.15	6.74
	Fertilizer input price	-5.33	4.77	-1.12	0.27	-15.09	4.42	0.46	2.15
1	Availability of fertilizer	22.46	8.21	2.74	0.01	5.67	39.25	0.36	2.74
	Access to fertilizer credit	4.50	8.39	0.54	0.60	-12.65	21.65	0.48	2.08
	Contact with DAs	24.17	4.82	5.01	0.000	14.31	34.03	0.20	4.99
	Total on-farm Income	0.001	0.000	3.29	0.003	0.00	0.002	0.17	5.75
	Total off-farm	0.001	0.001	1.28	0.21	0.00	0.003	0.55	1.83
	Soil fertility status of farmland	2.81	5.89	0.48	0.64	-9.25	14.86	0.21	4.81

DISCUSSION

The effect of each significant explanatory variable on the rate of inorganic fertilizer use in the two districts is discussed in the following.

Ownership of oxen (OXEN)

It significantly ($P \leq 0.005$) affects the adoption of inorganic fertilizer in both districts and with each additional percent of oxen, the probability of fertilizer adoption decreased by 5.994% in Boricha and by 9.728% in Wondogenet districts (Tables 6 and 7). This implies that adoption of inorganic fertilizer was less attractive to farmers who had large number of oxen owned and an increase in the number of oxen could lead farmers to shift in fattening of animals that would discouraged them to use oxen for ploughing which in turn decrease the adoption of inorganic fertilizer. It might also be due to the fact that an increase in the number of oxen would increase the availability of animal dung for organic manure preparation as reported in Yara International (2014).

Cultivated farm size (CFARMS)

It depicted a 1 ha increase in the size of cultivated land increased the adoption level of inorganic fertilizer by 15.87 kg in Boricha and 23.665 kg in Wondogenet districts (Tables 6 and 7). This indicates a farmer owned larger cultivated farm lands mean more resources and greater capacity to purchase fertilizer as well as it increases readiness to take risk in case of crop failure. It corroborates the works of Stanfrod News (2018).

Amount of certified seed given in kilogram (SEED)

This shows that 1 kg increase in the quantity of certified seed demanded, can lead to an increase in the amount of

Table 7. Multiple linear regression coefficients after multicollinearity problem correction for Wondogenet.

Model		Unstandardized Coefficients		t	Sig.	95% Confidence Interval for B		Collinearity Statistics	
		B	Std. Error			Lower Bound	Upper Bound	Tolerance	VIF
1	(Constant)	-32.98	13.92	-2.37	0.02	-61.41	-4.55	-	-
	Family labour force	1.98	2.63	0.75	0.46	-3.39	7.35	0.48	2.08
	Number of oxen owned	-9.73	3.74	-2.60	0.01	-17.37	-2.08	0.38	2.64
	Cultivated Farm Size	23.66	9.71	2.44	0.02	3.82	43.50	0.17	5.83
	Farming experience	-0.73	0.47	-1.57	0.13	-1.69	.22	0.57	1.74
	Manure application	10.40	6.42	1.62	0.12	-2.71	23.51	0.57	1.76
	availability of fertilizer	20.17	8.72	2.31	0.03	2.36	37.98	0.60	1.67
	Access to fertilizer credit	-0.91	5.86	-0.16	0.88	-12.88	11.06	0.70	1.42
	Contact with DAs	41.73	3.21	13.9	0.00	35.16	48.30	0.17	5.79
	Total on-Farm Income	.002	.001	2.00	0.05	0.000	0.004	0.19	5.21

fertilizer adoption by 4.029 kg in Boricha district (Table 6). Thus, a farmer who owned relatively higher amount of certified seed has more demand for fertilizer adoption than the one who owned smaller one which agrees with finding of Minor (2015) and World Bank (2016). For Wondogenet district, this variable has been omitted from being regressed in the regression model due to the multicollinarity remedial measurement.

On-time availability of fertilizer supply (ONTIME)

The present result revealed that on time supply of inorganic fertilizer could increase its adoption by 22.46% in Boricha and 20.17% in Wondogenet districts (Tables 6 and 7). This shows that supply of fertilizers at the time when farmers are in demand increases its adoption; otherwise its adoption level could discouraged if not available on-time as reported by Stewart and Roberts (2014).

Frequency of contact with DAs (FRCNT)

It was observed that a one-time increase in the number of contact would increase the amount of inorganic fertilizer by 24.173 kg in Boricha and by 41.730 kg in Wondogenet districts (Tables 6 and 7). This shows a farmer who has more frequent contact with DAs is supposed to access for information that enables s/he to assess the advantages of adopting inorganic fertilizer than those who contact less frequently and is more likely to adopt which agrees with the report of Akpan et al. (2013) and Bul Agric (2016).

Total on-farm income (ONFI)

Tables 6 and 7 show an increase in the total on-farm income by 1 birr could increase the amount of inorganic fertilizer adoption by 0.001 kg in Boricha and 0.002 kg in Wondogenet districts. This indicates as total on-farm income of the farmer's increases, their demand for adoption also increases in both districts. The result was in conformity with the earlier study of Dillon and Barrett (2017).

In general, the model from this study for each district was: $Y= -35.32-5.99X_1 + 15.87X_2 + 4.03X_3 +22.46X_4 + 24.17X_5 + 0.001X_6 + E$ for Boricha district and $Y= -32.98 - 9.72x_1 + 23.66x_2 + 20.17x_3 + 41.73x_4 + 0.002x_5 + E$ for Wondogenet district. Where the capital letters X_1, X_2, X_3, X_4, X_5, and X_6 represent number of oxen owned (OXEN), cultivated farm size (CFARMS), access to certified seed variety (SEED), on time availability of fertilizer supply (ONTIME), frequency of contact with DAs (FRCNT), and total on-farm income (ONFI) were identified significant explanatory variables in Boricha district. While the small letters x_1, x_2, x_3, x_4, and x_5 represent number of oxen owned (OXEN), cultivated farm size (CFARMS), on time availability of fertilizer supply (ONTIME), frequency of contact with DAs (FRCNT), and total on-farm income (ONFI), were also significant explanatory variables in Wondogenet district. Y denotes amount of inorganic fertilizer needed to be adopted by the farmers in kilogram and E represents the error terms.

Conclusion

Generally, from this research, it was found that older farmers were more adopters than younger ones. Educated farmers were observed adopting more than uneducated ones. Farmers who owned larger farm size were more adopters than those who owned smaller farm size in both districts. Farmers with larger number of livestock holdings used inorganic fertilizers more than those with smaller holdings.

Conclusively, appropriate and adequate extension services should be provided to promote the use of inorganic fertilizer to boost crop productivity to bridge the prevalent wide food deficit in the study districts. There should be well designed capacity building program to train additional DAs to reduce the existing higher ratio of farmers to DAs. The livestock ownership of the farmers shall be improved by capacitating the existing veterinary services as livestock holding is a proxy to wealth and has a positive effect on farmers demand for adopting technologies in the study area. Adequate rural finance institutions should also exist for better fertilizer credit facility as access to fertilizer credit has a positive influence on farmers' demand for inorganic fertilizer use.

In the study, the factors identified and analyzed were area specific and limited. Thus, understanding other and newly existing issues for the slow growth rate of inorganic fertilizer consumption should be further investigated in the future.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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